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AMERICAN MACHINISTS' HANDBOOK

American Machinists' Handbook

AND

DICTIONARY OF SHOP TERMS

A REFERENCE BOOK OF MACHINE-SHOP AND DRAWING-ROOM DATA, METHODS AND DEFINITIONS

BY

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EIGHTH EDITION
REVISED AND ENLARGED

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PREFACE TO THE EIGHTH EDITION

In bringing the handbook up to date it has been necessary to omit some of the older tables and add many new ones. This has added many new tables to the first section (screw threads), and 38 pages of material. Much of the addition deals with the new standards of truncated Whitworth threads, brought out during the war, as an aid in securing interchangeability between threads made with the regular round top and bottom of the Whitworth, and with a modified thread having a flat or truncated top and bottom. This includes gages for the modified thread and drill tables for tapping for this modified thread.

The new material includes the latest data on wire measurement of screw threads and gives the specifications for wires if satisfactory fits are to be secured in mass production. Some of the tables for American Standard threads have also been modified and the new tables have replaced the ones which have been discarded. These data were secured direct from the Bureau of Standards in Washington. Other standards, such as those for involute splines, are also very new, having been secured just after their release for publication.

Extensive changes will be noted in the section on milling practice, which has undergone drastic changes since the last edition. We are fortunate in being able to secure late research data from the leading makers of milling machines and cutters, as well as the results of the practical use of negative-rake carbide tools for milling and turning. There is also considerable new material on bevel and other gearing. Much new data will be found scattered throughout this edition on a variety of subjects.

THE AUTHORS.

August, 1945.

PREFACE TO THE FIRST EDITION

EVERY man engaged in mechanical work of any kind, regardless of his position in the shop or drawing room, frequently requires information that is seldom remembered and is not usually available when wanted.

With this in mind it has been our endeavor to present in convenient form such data as will be of value to practical men in the various branches of machine work. While some of the matter included may seem elementary, it was considered necessary in order to make the work complete. Much of the information has never before been available to the mechanic without tiresome search and consultation.

We believe that the Dictionary section will be found of service to the younger mechanics and in helping to establish standard names for various parts which are now more or less confused in different sections of the country.

Our indebtedness to various manufacturers and individuals is hereby acknowledged, and in the back of the book will be found a list of such authorities with page references to the information furnished by them.

We dare not hope that no errors will be found and we shall be glad to have them pointed out and to receive any suggestions as to additions or other changes which may add to the value of the book.

THE AUTHORS.

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AMERICAN MACHINISTS' HANDBOOK

SECTION I

SCREW THREADS

Screw threads are so widely used as a connection between parts that commercial interchangeability is necessary in all mechanical fields. This is more difficult than with plain fits because three elements are involved, namely, pitch diameter, angle of the sides of the thread, and lead. These are all considered in the standardization work that has been done.

Since threads have been called by different names, it is essential that these terms be understood to avoid confusion. The sharp V thread is rarely used. The flat-top thread was originally called the Sellers, also the Franklin Institute thread, and later the United States Standard. None of these standards recognized tolerances, which are necessary for good fits. The standard now in use in this country is known as the American National Standard. It retains the Sellers form and proportions but includes tolerances of lead, pitch diameter, and angle. It also includes the finer pitches developed for the automobile industry. There is also an extra-fine set of pitches for special work.

THREAD FORMS AND TOLERANCES

The data and tables that follow represent many years' work on the part of committees of the A.S.M.E. and the S.A.E. as well as the National Screw Thread Commission. The definitions and tables which follow give the latest data available regarding standard screw threads. Neither the root nor the outside diameter is important, except that they must not bear in the mating part.

Thread measurement now deals principally with the pitch diameter and lead, the three-wire method superseding the two-wire, and the optical method also gaining in favor. The tables show the standard dimensions and tolerances for threads of different degrees of accuracy. It is urged that these tolerances be specified and used in all cases, selecting the kind of fit required by the work in hand. Tables of the new standards are included in this section beginning on page 8. Thread form and name of parts are shown in Fig. 1.

AMERICAN STANDARD SCREW THREADS FOR BOLTS, MACHINE SCREWS, NUTS, AND COMMERCIALLY TAPPED HOLES

This section is from the report of a Committee on the Standardization and Unification of Screw Threads prepared in collaboration with the National Screw Thread Commission, the A.S.M.E. and the S.A.E. and approved by the American Engineering Standard Committee in April, 1933.

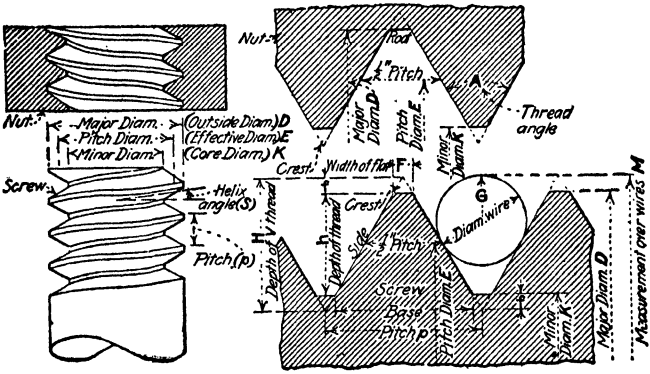

FIG. 1.—Screw Thread Parts

TERMS RELATING TO SCREW THREADS

Screw Thread.—A ridge of uniform section in the form of a helix on the external or internal surface of a cylinder or cone.

External Thread.—An external thread is a thread on the outside of a member.

Internal Thread.—An internal thread is a thread on the inside of a member.

Major Diameter.—The largest diameter of a screw thread. The term "major diameter" replaces the term "outside diameter" as applied to the thread of a screw and also the term "full diameter" as applied to the thread of a nut.

Minor Diameter.—The smallest diameter of a screw thread. The term "minor diameter" replaces the terms "core diameter" and "root diameter" as applied to the thread of a screw and also the term "inside diameter" as applied to the thread of a nut.

Pitch Diameter.—On a straight screw thread the diameter of an imaginary cylinder, the surface of which would pass through the threads at such points as to make equal the width of the threads and the width of the spaces cut by the surface of the cylinder.

Pitch.—The distance from a point on a screw thread to a corresponding point on the next thread measured parallel to the axis.

$$\text{Pitch (in inches)} = \frac{1}{\text{number of threads per inch}}.$$

Lead.—The distance a screw thread advances axially in one turn. On a single-thread screw, the lead and pitch are identical; on a double-thread screw, the lead is twice the pitch; on a triple-thread screw, the lead is three times the pitch, etc.

Angle of Thread.—The angle included between the sides of the thread measured in an axial plane.

Helix Angle.—The angle made by the helix of the thread at the pitch diameter with a plane perpendicular to the axis.

Crest.—The top surface joining the two sides of a thread.

Root.—The bottom surface joining the sides of two adjacent threads.

Side.—The surface of the thread which connects the crest with the root.

Axis of a Screw.—The longitudinal central line through the screw.

Depth of Thread.—The distance between the crest and the root of thread measured normally to the axis.

Length of Engagement.—The length of contact between two mating parts, measured axially.

Depth of Engagement.—The depth of thread contact of two mating parts, measured radially.

TERMS RELATING TO CLASSIFICATION OF FITS

Basic.—The theoretical or nominal standard size from which all variations are made.

Crest Clearance.—Defined on a screw form as the space between the crest of a thread and the root of its mating thread.

Allowance.—An intentional difference in the dimensions of mating parts. It is the minimum clearance or the maximum interference which is intended between mating parts.

Tolerance.—The amount of variation permitted in the size of a part.

Neutral Zone.—A positive allowance (see Allowance).

Limits.—The extreme permissible dimensions of a part.

Fit.—The relation between two mating parts with reference to ease of assembly; for example, wrench fit, close fit, medium fit, free fit. The quality of fit is dependent upon both the relative size and the quality of finish of the mating parts.

Finish.—The character of the surface on a screw thread.

SYMBOLS

Dimensional Symbols.—For use in formulas for expressing relations of screw threads and for use on drawings and for similar purposes the following dimensional symbols should be used:

Major diameter	D
Corresponding radius	d
Pitch diameter	E
Corresponding radius	e
Minor diameter	K
Corresponding radius	k
Angle of thread	A
One-half angle of thread	a
Number of turns per inch	N
Number of threads per inch	n
Lead	$L = \frac{1}{N}$
Pitch or thread interval	$p = \frac{1}{n}$
Helix angle	s
Tangent of helix angle	$S = \frac{L}{3.14159 \times E}$
Width of basic flat at top crest or root	F
Depth of basic truncation	f
Depth of sharp V thread	H
Depth of American (National) form of thread	h

SYMBOLS FOR WIRE MEASUREMENTS

Measurement over wires	M
Diameter of wire	G
Corresponding radius	g

Identification Symbols.—These are for use on correspondence, drawings, shop and storeroom cards, specifications for parts, taps, dies, gages, etc., and on the tools and gages themselves.

The basis of the system is the initial letters of the series, preceded by the diameter in inches (or the screw number) and number of threads per inch followed by the classification of fit, all in Arabic characters. If the thread is left-hand, the symbol "L. H." shall follow the number of threads. No symbol is used to distinguish right-hand threads.

Examples	Mark
American (National) coarse-thread system: To specify a threaded part 1 inch in diameter, 8 threads per inch, and Class 2 fit.	1″–8–NC–2
American (National) fine-thread system: A threaded part 1 inch in diameter, 14 threads per inch, left-hand thread, and Class 4 fit.	1″–14–LH–NF–4
American (National) form, special pitch: A threaded part 1 inch in diameter, 12 threads per inch, and Class 3 fit.	1″–12–N–3

Note.—The number of threads per inch must be indicated in all cases, irrespective of whether it is the standard number of threads for that particular size of threaded part or special.

Form of Thread

The form of thread profile as specified herein, and known previously as the United States Standard or Sellers Profile, is adopted and shall hereafter be known as the American National form of thread.

Specifications.—The basic angle of thread between the sides of the thread measured in an axial plane shall be 60 degrees. The line bisecting this 60-degree angle shall be perpendicular to the axis of the screw thread.

The basic width of flat at the root and crest of the thread form is found as follows:

$$F = \tfrac{1}{8} \times p \quad \text{or} \quad 0.125 \times p.$$

The basic depth of the thread form is found as follows:

$$h = 0.649519 \times p = \frac{0.649519}{n}$$

where p = pitch in inches.
n = number of threads per inch.

Clearance in Nut at Minor Diameter.—A clearance shall be provided at the minor diameter of the nut by removing the thread form at the crest by an amount between one-sixth and one-fourth of the basic thread depth.

Clearance in Nut at Major Diameter.—A clearance at the major diameter of the nut shall be provided by decreasing the depth of the truncation triangle any desired amount down to one-third of its theoretical value.

Thread Series Adopted

Two thread series are adopted—a coarse and a fine. The Coarse-Thread Series is the present "United States Standard" supple-

mented in the sizes below ¼ inch by a part of the standard established by the American Society of Mechanical Engineers (A.S.M.E.) in 1907. The Fine-Thread Series (¼ to 1½ inches inclusive) was originally the A.L.A.M. and later the S.A.E. standard. These, together with the Extra Fine and the 8-, 12-, and 16-pitch series, are now A.S.A. (American Standards Association) standards as of February 10, 1943.

These two series are specified in Table 1.

TABLE 1.—THE TWO-THREAD SERIES

1	2	3	4		5	6	
Sizes	Basic Major Diameter in Inches	Coarse Series, Threads per Inch	Helix Angle at Pitch Diameter		Fine Series, Threads per Inch	Helix Angle at Pitch Diameter	
			Degrees	Minutes		Degrees	Minutes
0	0.0600				80	4	23
1	0.0730	64	4	31	72	3	57
2	0.0860	56	4	22	64	3	45
3	0.0990	48	4	26	56	3	43
4	0.1120	40	4	25	48	3	51
5	0.1250	40	4	11	44	3	45
6	0.1380	32	4	50	40	3	44
8	0.1640	32	3	58	36	3	28
10	0.1900	24	4	39	32	3	21
12	0.2160	24	4	1	28	3	22
¼	0.2500	20	4	11	28	2	52
5/16	0.3125	18	3	40	24	2	40
⅜	0.3750	16	3	24	24	2	11
7/16	0.4375	14	3	20	20	2	15
½	0.5000	13	3	7	20	1	57
9/16	0.5625	12	2	59	18	1	55
⅝	0.6250	11	2	56	18	1	43
¾	0.7500	10	2	40	16	1	36
⅞	0.8750	9	2	31	14	1	34
1	1.0000	8	2	29	14	1	22
1⅛	1.1250	7	2	31	12	1	25
1¼	1.2500	7	2	15	12	1	16
1½	1.5000	6	2	11	12	1	3
1¾	1.7500	5	2	15	12[1]		
2	2.0000	4½	2	11	12[1]		
2¼	2.2500	4½	1	55	12[1]		
2½	2.5000	4	1	57	12[1]		
2¾	2.7500	4	1	46	12[1]		
3	3.0000	4	1	36	10[1]		
3¼	3.2500	4	1	29			
3½	3.5000	4	1	22			
3¾	3.7500	4	1	16			
4	4.0000	4	1	11			

CLASSIFICATION OF FITS

Four distinct classes of screw-thread fits are established for general use, as specified in the following brief outline. The examples given under each class of fit are for the purpose of illustration only.

Loose Fit (**Class 1**).—Recommended as a commercial standard for tapped holes in the numbered sizes only. May be used with screws of other classes to obtain quality of fit desired.

Free Fit (**Class 2**).—Includes the great bulk of screw-thread work of ordinary quality of finished and semi-finished bolts and nuts, etc. (called "Medium Fit Regular" in the N.S.T.C. "Progress Report").

Medium Fit (**Class 3**).—Includes the better grade of interchangeable screw-thread work, such as automobile bolts and nuts (called "Medium Fit Special" in N.S.T.C. "Progress Report").

Close Fit (**Class 4**).—Includes screw-thread work requiring a fine snug fit, somewhat closer than the medium fit, such as high-grade aircraft parts, etc. In this class of fit, selective assembly of parts may be required. It is not considered practicable as a commercial standard for tapped holes of the numbered sizes.

A Second Method of Obtaining Medium Fit (Class 3)

A detailed examination of the tolerances given in Tables 3, 4, and 5 will indicate that the same quality of fit as given by medium-fit screws and threaded holes can be obtained by using screws to close fit tolerances in holes made to free fit tolerances, or *vice versa* The general adoption of this practice will reduce the variety of taps, gages, threaded parts, etc., required to be carried in stock. However, the combination of free and close fits should be used in place of medium fit only when the substitution is understood and agreed to by all parties concerned.

Conditions Requiring Special Fits.—In cases where looser fits are required than those given by the above-named classes, the use of the loose fit of the National Screw Thread Commission is recommended.

Rounded Root Forms.—The crest clearances allowed are such as to permit rounded root forms in both nut and screw. These may be formed either by tools purposely rounded or rounded as a result of wear in use. For the limits of this permissible rounding see Tolerances, page 16.

DEFINITIONS

Loose Fit (**Class 1**).—This class of screw threads is, in this report, recommended for use in tapped holes in the *numbered sizes only*. For such use it will be defined and specified as follows:

Minimum nut is basic.

Direction of tolerance on nut: The tolerance on the nut will be plus.

Tolerance values: The tolerances for a nut of a given pitch will be as specified in Table 2.

Free Fit (**Class 2**).—This class of screw threads will be defined and specified as follows:

Minimum nut is basic.

Maximum screw is basic.

Direction of tolerance on nut: The tolerance on the nut will be plus.

Direction of tolerance on screw: The tolerance on the screw will be minus.

Zero allowance: The allowance between the pitch diameter of the maximum screw and minimum nut will be zero for all pitches and all diameters.

Tolerance values: The tolerances for a screw or nut of a given pitch will be specified in Table 3.

Medium Fit (Class 3).—This class of screw threads will be defined and specified as follows:

Minimum nut is basic.

Maximum screw is basic.

Direction of tolerance on nut: The tolerance on the nut will be plus.

Direction of tolerance on screw[1]: The tolerance on the screw will be minus.

Zero allowance: The allowance between the pitch diameter of the maximum screw and the minimum nut will be zero for all pitches and all diameters.

Tolerance values: The tolerances for a screw or nut of a given pitch will be specified in Table 4.

Close Fit (Class 4).—This class of screw threads will be defined and specified as follows:

Minimum nut is basic.

Maximum screw is above basic: The major diameter and pitch diameter of the maximum screw will be above dimensions by the amount of the negative allowance (interference) specified in Table 5.

Direction of tolerance on nut: The tolerance on the nut will be plus.

Direction of tolerance on screw: The tolerance on the screw will be minus.

Allowance values: The negative allowance (interference) provided between the pitch diameter of the minimum nut, which is basic, and that of the maximum screw, which is above basic, will be as specified in Table 5.

Tolerance values: The tolerance for a screw or nut of a given pitch will be as specified in Table 5.

TOLERANCES

Tolerances Represent Extreme Variations.—The tolerances as hereinafter specified are for the classes of fit listed in the body of the report, and represent the extreme variations allowed on the work. They are shown in Fig. 2.

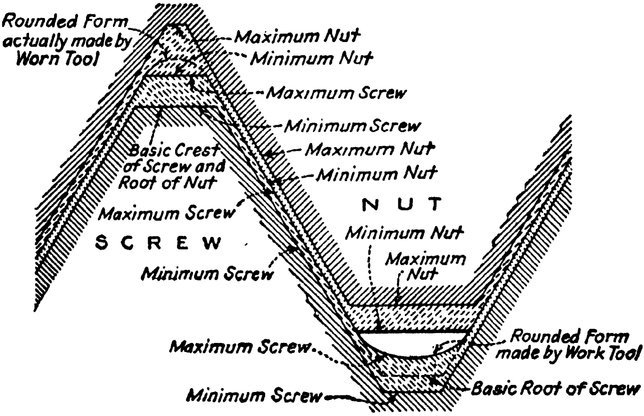

FIG. 2.—Illustrating Tolerances and Crest Clearances for Free and Medium Fits (Classes 2 and 3)

Pitch-Diameter Tolerances.—These are derived from the pitch of the thread instead of from the diameter. The method of derivation is explained on page 21.

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[1] The maximum minor diameter of the screw is above the basic minor diameter.

(Text continues on page 20.)

TABLE 2.—AMERICAN NATIONAL COARSE-THREAD SERIES

Identification	Basic Diameters					Thread Data						
Sizes, in Inches	Threads per Inch, n	Major Diameter, D, in Inches	Pitch Diameter, E, in Inches	Minor Diameter, K, in Inches	Metric Equivalent of, Major Diameter, in Millimeters	Pitch, p, in Inches	Depth of Thread, h, in Inches	Basic Width of Flat, $\frac{p}{8}$ in Inches	Minimum Width of Flat at Major Diameter of Nut, $\frac{p}{24}$, in Inches	Helix Angle of Basic Pitch Diameter, s		Basic Area of Section at Root of Thread, $\frac{\pi K^2}{4}$, in Square Inches
										Deg.	Min.	
1	64	0.073	0.0629	0.0527	1.854	0.01562	0.01015	0.00195	0.00065	4	31	0.0022
2	56	0.086	0.0744	0.0628	2.184	0.01786	0.01160	0.00223	0.00074	4	22	0.0031
3	48	0.099	0.0855	0.0719	2.515	0.02083	0.01353	0.00260	0.00087	4	26	0.0041
4	40	0.112	0.0958	0.0795	2.845	0.02500	0.01624	0.00312	0.00104	4	45	0.0050
5	40	0.125	0.1088	0.0925	3.175	0.02500	0.01624	0.00312	0.00104	4	11	0.0067
6	32	0.138	0.1177	0.0974	3.505	0.03125	0.02030	0.00391	0.00130	4	50	0.0075
8	32	0.164	0.1437	0.1234	4.166	0.03125	0.02030	0.00391	0.00130	3	58	0.0120
10	24	0.190	0.1629	0.1359	4.826	0.04167	0.02706	0.00521	0.00174	4	39	0.0145
12	24	0.216	0.1889	0.1619	5.486	0.04167	0.02706	0.00521	0.00174	4	1	0.0206
$\frac{1}{4}$	20	0.2500	0.2175	0.1850	6.350	0.05000	0.03248	0.00625	0.00208	4	11	0.0269
$\frac{5}{16}$	18	0.3125	0.2764	0.2403	7.938	0.05556	0.03608	0.00694	0.00231	3	40	0.0454
$\frac{3}{8}$	16	0.3750	0.3344	0.2938	9.525	0.06250	0.04059	0.00781	0.00260	3	24	0.0678
$\frac{7}{16}$	14	0.4375	0.3911	0.3447	11.113	0.07143	0.04639	0.00893	0.00298	3	20	0.0933
$\frac{1}{2}$	13	0.5000	0.4500	0.4001	12.700	0.07692	0.04996	0.00962	0.00321	3	7	0.1257
$\frac{9}{16}$	12	0.5625	0.5084	0.4542	14.288	0.08333	0.05413	0.01042	0.00347	2	59	0.1620
$\frac{5}{8}$	11	0.6250	0.5660	0.5069	15.875	0.09091	0.05905	0.01136	0.00379	2	56	0.2018

TABLE 2.—AMERICAN NATIONAL COARSE-THREAD SERIES.—*Continued*

Identification	Basic Diameters					Thread Data						
Sizes, in Inches	Threads per Inch, n	Major Diameter, D, in Inches	Pitch Diameter, E, in Inches	Minor Diameter, K, in Inches	Metric Equivalent of, Major Diameter, in Millimeters	Pitch, p, in Inches	Depth of Thread, h, in Inches	Basic Width of Flat, $\frac{p}{8}$ in Inches	Minimum Width of Flat at Major Diameter of Nut, $\frac{p}{24}$, in Inches	Helix Angle of Basic Pitch Diameter, s		Basic Area of Section at Root of Thread, $\frac{\pi K^2}{4}$, in Square Inches
										Deg.	Min.	
$\frac{3}{4}$	10	0.7500	0.6850	0.6201	19.050	0.10000	0.06495	0.01250	0.00417	2	40	0.3020
$\frac{7}{8}$	9	0.8750	0.8028	0.7307	22.225	0.11111	0.07217	0.01389	0.00463	2	31	0.4193
1	8	1.0000	0.9188	0.8376	25.400	0.12500	0.08119	0.01562	0.00521	2	29	0.5510
$1\frac{1}{8}$	7	1.1250	1.0322	0.9394	28.575	0.14286	0.09279	0.01786	0.00595	2	31	0.6931
$1\frac{1}{4}$	7	1.2500	1.1572	1.0644	31.750	0.14286	0.09279	0.01786	0.00595	2	15	0.8898
$1\frac{3}{8}$	6	1.3750	1.2667	1.1585	34.925	0.16667	0.10825	0.02083	0.00694	2	24	1.0541
$1\frac{1}{2}$	6	1.5000	1.3917	1.2835	38.100	0.16667	0.10825	0.02083	0.00694	2	11	1.2938
$1\frac{3}{4}$	5	1.7500	1.6201	1.4902	44.450	0.20000	0.12990	0.02500	0.00833	2	15	1.7441
2	$4\frac{1}{2}$	2.0000	1.8557	1.7113	50.800	0.22222	0.14434	0.02778	0.00926	2	11	2.3001
$2\frac{1}{4}$	$4\frac{1}{2}$	2.2500	2.1057	1.9613	57.150	0.22222	0.14434	0.02778	0.00926	1	55	3.0212
$2\frac{1}{2}$	4	2.5000	2.3376	6.1752	63.500	0.25000	0.16238	0.03125	0.01042	1	57	3.7161
$2\frac{3}{4}$	4	2.7500	2.5876	2.4252	69.850	0.25000	0.16238	0.03125	0.01042	1	46	4.6194
3	4	3.0000	2.8376	2.6752	76.200	0.25000	0.16238	0.03125	0.01042	1	36	5.6209
$3\frac{1}{4}$	4	3.2500	3.0876	2.9252	82.550	0.25000	0.16238	0.03125	0.01042	1	29	6.7205
$3\frac{1}{2}$	4	3.5000	3.3376	3.1752	88.900	0.25000	0.16238	0.03125	0.01042	1	22	7.9183
$3\frac{3}{4}$	4	3.7500	3.5876	3.4252	95.250	0.25000	0.16238	0.03125	0.01042	1	16	9.2143
4	4	4.0000	3.8376	3.6752	101.600	0.25000	0.16238	0.03125	0.01042	1	11	10.6084

TABLE 3.—LIMITING DIMENSIONS AND TOLERANCES, CLASSES 1, 2, 3, AND 4 FITS, AMERICAN NATIONAL COARSE-THREAD SERIES

Dimensions and Tolerances, in Inches		Machine Screw Number or Nominal Size										
		1	2	3	4	5	6	8	10	12	1/4	5/16
		Threads per Inch										
		64	56	48	40	40	32	32	24	24	20	18
BOLTS AND SCREWS												
Class 1, major diameter	Max.	0.0723	0.0852	0.0981	0.1110	0.1240	0.1369	0.1629	0.1887	0.2147	0.2485	0.3109
	Min.	0.0671	0.0796	0.0919	0.1042	0.1172	0.1293	0.1553	0.1795	0.2055	0.2383	0.2995
	Tol.	0.0052	0.0056	0.0062	0.0068	0.0068	0.0076	0.0076	0.0092	0.0092	0.0102	0.0114
Classes 2, 3, and 4, major diameter	Max.	0.0730	0.0860	0.0990	0.1120	0.1250	0.1380	0.1640	0.1900	0.2160	0.2500	0.3125
	Min.	0.0692	0.0820	0.0946	0.1072	0.1202	0.1326	0.1586	0.1834	0.2094	0.2428	0.3043
	Tol.	0.0038	0.0040	0.0044	0.0048	0.0048	0.0054	0.0054	0.0066	0.0066	0.0072	0.0082
Class 2, major diameter (threaded parts of unfinished, hot-rolled material)	Max.	0.0730	0.0860	0.0990	0.1120	0.1250	0.1380	0.1640	0.1900	0.2160	0.2500	0.3125
	Min.	0.0678	0.0804	0.0928	0.1052	0.1182	0.1304	0.1564	0.1808	0.2068	0.2398	0.3011
	Tol.	0.0052	0.0056	0.0062	0.0068	0.0068	0.0076	0.0076	0.0092	0.0092	0.0102	0.0114
Class 1, minor diameter	Max.[1]	0.0531	0.0633	0.0725	0.0803	0.0933	0.0986	0.1246	0.1376	0.1636	0.1872	0.2427
Classes 2, 3, and 4, minor diameter	Max.[1]	0.0538	0.0641	0.0734	0.0813	0.0943	0.0997	0.1257	0.1389	0.1649	0.1887	0.2443
Class 1, pitch diameter	Max.	0.0622	0.0736	0.0846	0.0948	0.1078	0.1166	0.1426	0.1616	0.1876	0.2160	0.2748
	Min.	0.0596	0.0708	0.0815	0.0914	0.1044	0.1128	0.1388	0.1570	0.1830	0.2109	0.2691
	Tol.	0.0026	0.0028	0.0031	0.0034	0.0034	0.0038	0.0038	0.0046	0.0046	0.0051	0.0057
Class 2, pitch diameter	Max.	0.0629	0.0744	0.0855	0.0958	0.1088	0.1177	0.1437	0.1629	0.1889	0.2175	0.2764
	Min.	0.0610	0.0724	0.0833	0.0934	0.1064	0.1150	0.1410	0.1596	0.1856	0.2139	0.2723
	Tol.	0.0019	0.0020	0.0022	0.0024	0.0024	0.0027	0.0027	0.0033	0.0033	0.0036	0.0041

TABLE 3.—LIMITING DIMENSIONS AND TOLERANCES, CLASSES 1, 2, 3, AND 4 FITS, AMERICAN NATIONAL COARSE-THREAD SERIES.—*Continued*

Dimensions and Tolerances, in Inches		Machine Screw Number or Nominal Size										
		1	2	3	4	5	6	8	10	12	1/4	5/16
		Threads per Inch										
		64	56	48	40	40	32	32	24	24	20	18
Class 3, pitch diameter	Max.	0.0629	0.0744	0.0855	0.0958	0.1088	0.1177	0.1437	0.1629	0.1889	0.2175	0.2764
	Min.	0.0615	0.0729	0.0839	0.0941	0.1071	0.1158	0.1418	0.1605	0.1865	0.2149	0.2734
	Tol.	0.0014	0.0015	0.0016	0.0017	0.0017	0.0019	0.0019	0.0024	0.0024	0.0026	0.0030
Class 4, pitch diameter	Max.	......	......	......	......	......	......	......	......	......	0.2178	0.2767
	Min.	......	......	......	......	......	......	......	......	......	0.2165	0.2752
	Tol.	......	......	......	......	......	......	......	......	......	0.0013	0.0015
NUTS AND TAPPED HOLES												
Classes 1, 2, 3, and 4, major diameter	Min.[2]	0.0730	0.0860	0.0990	0.1120	0.1250	0.1380	0.1640	0.1900	0.2160	0.2500	0.3125
Classes 1, 2, 3, and 4, minor diameter	Max.[3]	0.0623	0.0737	0.0841	0.0938	0.1062	0.1145	0.1384	0.1559	0.1801	0.2060	0.2630
	Min.	0.0561	0.0667	0.0764	0.0849	0.0979	0.1042	0.1302	0.1449	0.1709	0.1959	0.2524
	Tol.	0.0062	0.0070	0.0077	0.0089	0.0083	0.0103	0.0082	0.0110	0.0092	0.0101	0.0106
Classes 1, 2, 3, and 4, pitch diameter	Min.	0.0629	0.0744	0.0855	0.0958	0.1088	0.1177	0.1437	0.1629	0.1889	0.2175	0.2764
Class 1, pitch diameter	Max.[4]	0.0655	0.0772	0.0886	0.0992	0.1122	0.1215	0.1475	0.1675	0.1935	0.2226	0.2821
	Tol.	0.0026	0.0028	0.0031	0.0034	0.0034	0.0038	0.0038	0.0046	0.0046	0.0051	0.0057
Class 2, pitch diameter	Max.[4]	0.0648	0.0764	0.0877	0.0982	0.1112	0.1204	0.1464	0.1662	0.1922	0.2211	0.2805
	Tol.	0.0019	0.0020	0.0022	0.0024	0.0024	0.0027	0.0027	0.0033	0.0033	0.0036	0.0041
Class 3, pitch diameter	Max.[4]	0.0643	0.0759	0.0871	0.0975	0.1105	0.1196	0.1456	0.1653	0.1913	0.2201	0.2794
	Tol.	0.0014	0.0015	0.0016	0.0017	0.0017	0.0019	0.0019	0.0024	0.0024	0.0026	0.0030
Class 4, pitch diameter	Max.[4]	......	......	......	......	......	......	......	......	......	0.2188	0.2779
	Tol.	......	......	......	......	......	......	......	......	......	0.0013	0.0015

See footnotes at end of table.

TABLE 3.—LIMITING DIMENSIONS AND TOLERANCES, CLASSES 1, 2, 3, AND 4 FITS, AMERICAN NATIONAL COARSE-THREAD SERIES.—*Continued*

Dimensions and Tolerances, in Inches		Machine Screw Number or Nominal Size										
		3/8	7/16	1/2	9/16	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8
		Threads per Inch										
		16	14	13	12	11	10	9	8	7	7	6
BOLTS AND SCREWS												
Class 1, major diameter	Max.	0.3732	0.4354	0.4978	0.5601	0.6224	0.7472	0.8719	0.9966	1.1211	1.2461	1.3706
	Min.	0.3606	0.4214	0.4830	0.5443	0.6054	0.7288	0.8519	0.9744	1.0963	1.2213	1.3416
	Tol.	0.0126	0.0140	0.0148	0.0158	0.0170	0.0184	0.0200	0.0222	0.0248	0.0248	0.0290
Classes 2, 3, and 4, major diameter	Max.	0.3750	0.4375	0.5000	0.5625	0.6250	0.7500	0.8750	1.0000	1.1250	1.2500	1.3750
	Min.	0.3660	0.4277	0.4896	0.5513	0.6132	0.7372	0.8610	0.9848	1.1080	1.2330	1.3548
	Tol.	0.0090	0.0098	0.0104	0.0112	0.0118	0.0128	0.0140	0.0152	0.0170	0.0170	0.0202
Class 2, major diameter (threaded parts of unfinished, hot-rolled material)	Max.	0.3750	0.4375	0.5000	0.5625	0.6250	0.7500	0.8750	1.0000	1.1250	1.2500	1.3750
	Min.	0.3624	0.4235	0.4852	0.5467	0.6080	0.7316	0.8550	0.9778	1.1002	1.2252	1.3460
	Tol.	0.0126	0.0140	0.0148	0.0158	0.0170	0.0184	0.0200	0.0222	0.0248	0.0248	0.0290
Class 1, minor diameter	Max.[1]	0.2965	0.3478	0.4034	0.4579	0.5109	0.6245	0.7356	0.8432	0.9458	1.0708	1.1661
Classes 2, 3, and 4, minor diameter	Max.[1]	0.2983	0.3499	0.4056	0.4603	0.5135	0.6273	0.7387	0.8466	0.9497	1.0747	1.1705
Class 1, pitch diameter	Max.	0.3326	0.3890	0.4478	0.5060	.05634	0.6822	0.7997	0.9154	1.0283	1.1533	1.2623
	Min.	0.3263	0.3820	0.4404	0.4981	0.5549	0.6730	.07897	0.9043	1.0159	1.1409	1.2478
	Tol.	0.0063	0.0070	0.0074	0.0079	0.0085	0.0092	0.0100	0.0111	0.0124	0.0124	0.0145
Class 2, pitch diameter	Max.	0.3344	0.3911	0.4500	0.5084	0.5660	0.6850	0.8028	0.9188	1.0322	1.1572	1.2667
	Min.	0.3299	0.3862	0.4448	0.5028	0.5601	0.6786	0.7958	0.9112	1.0237	1.1487	1.2566
	Tol.	0.0045	0.0049	0.0052	0.0056	0.0059	0.0064	0.0070	0.0076	0.0085	0.0085	0.0101

TABLE 3.—LIMITING DIMENSIONS AND TOLERANCES, CLASSES 1, 2, 3, AND 4 FITS, AMERICAN NATIONAL COARSE-THREAD SERIES—*Continued*

Dimensions and Tolerances, in Inches		Machine Screw Number or Nominal Size										
		3/8	7/16	1/2	9/16	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8
		Threads per Inch										
		16	14	13	12	11	10	9	8	7	7	6
Class 3, pitch diameter	Max.	0.3344	0.3911	0.4500	0.5084	0.5660	0.6850	.08028	0.9188	1.0322	1.1572	1.2667
	Min.	0.3312	0.3875	0.4463	0 5044	0.5618	0.6805	0.7979	0.9134	1.0263	1.1513	1.2596
	Tol.	0.0032	0.0036	0.0037	0.0040	0.0042	0.0045	0.0049	0.0054	0.0059	0.0059	0.0071
Class 4, pitch diameter	Max.	0.3348	0.3915	0.4504	0.5089	0.5665	0.6856	0.8034	0.9195	1.0330	1.1580	1.2676
	Min.	0.3332	0.3897	0.4485	0.5069	0.5644	0.6833	0.8010	0.9168	1.0300	1.1550	1.2640
	Tol.	0.0016	0.0018	0.0019	0.0020	0.0021	0.0023	0.0024	0.0027	0.0030	.00030	0.0036
NUTS AND TAPPED HOLES												
Classes 1, 2, 3, and 4, major diameter	Min.[2]	0.3750	0.4375	0.5000	0.5625	0.6250	0.7500	0.8750	1.0000	1.1250	1.2500	1.3750
Classes 1, 2, 3, and 4, minor diameter	Max.[3]	0.3184	0.3721	0.4290	0.4850	0.5397	0.6553	0.7689	0.8795	0.9858	1.1108	1.2126
	Min.	0.3073	0.3602	0.4167	0.4723	0.5266	0.6417	0.7547	0.8647	0.9704	1.0954	1.1946
	Tol.	0.0111	0.0119	0.0123	0.0127	0.0131	0.0136	0.0142	0.0148	0.0154	0.0154	0.0180
Classes 1, 2, 3, and 4, pitch diameter	Min.	0.3344	0.3911	0.4500	0.5084	0.5660	0.6850	0.8028	0.9188	1.0322	1.1572	1.2667
Class 1, pitch diameter	Max.[4]	0.3407	0.3981	0.4574	0.5163	0.5745	0.6942	0.8128	0.9299	1.0446	1.1696	1.2812
	Tol.	0.0063	0.0070	0.0074	0.0079	0.0085	0.0092	0.0100	0.0111	0.0124	0.0124	0.0145
Class 2, pitch diameter	Max.[4]	0.3389	0.3960	0.4552	0.5140	0.5719	0.6914	0.8098	0.9264	1.0407	1.1657	1.2768
	Tol.	0.0045	0.0049	0.0052	0.0056	0.0059	0.0064	0.0070	0.0076	0.0085	0.0085	0.0101
Class 3, pitch diameter	Max.[4]	0.3376	0.3947	0.4537	0.5124	0.5702	0.6895	0.8077	0.9242	1.0381	1.1631	1.2873
	Tol.	0.0032	0.0036	0.0037	0.0040	0.0042	0.0045	0.0049	0.0054	0.0059	0.0059	0.0071
Class 4, pitch diameter	Max.[4]	0.3360	0.3929	0.4519	0.5104	0.5681	0.6873	0.8052	0.9215	1.0352	1.1602	1.2703
	Tol.	0.0016	0.0018	0.0019	0.0020	.00021	0.0023	0.0024	0.0027	0.0030	0.0030	0.0036

See footnotes at end of table.

TABLE 3.—LIMITING DIMENSIONS AND TOLERANCES, CLASSES 1, 2, 3, AND 4 FITS, AMERICAN NATIONAL COARSE-THREAD SERIES.—*Continued*

Dimensions and Tolerances, in Inches		Size										
		1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4
		Threads per Inch										
		6	5	4½	4½	4	4	4	4	4	4	4
BOLTS AND SCREWS												
Class 1, major diameter	Max.	1.4956	1.7448	1.9943	2.2443	2.4936	2.7436	2.9936	3.2436	3.4936	3.7436	3.9936
	Min.	1.4666	1.7110	1.9575	2.2075	2.4528	2.7028	2.9528	3.2028	3.4528	3.7028	3.9528
	Tol.	0.0290	0.0338	0.0368	0.0368	0.0408	0.0408	0.0408	0.0408	0.0408	0.0408	0.0408
Classes 2, 3, and 4, major diameter	Max.	1.5000	1.7500	2.0000	2.2500	2.5000	2.7500	3.0000	3.2500	3.5000	3.7500	4.0000
	Min.	1.4798	1.7268	1.9746	2.2246	2.4720	2.7220	2.9720	3.2220	3.4720	3.7220	3.9720
	Tol.	0.0202	0.0232	0.0254	0.0254	0.0280	0.0280	0.0280	0.0280	0.0280	0.0280	0.0280
Class 2, major diameter (threaded parts of unfinished, hot-rolled material)	Max.	1.5000	a.7500	2.0000	2.2500	2.5000	2.7500	3.0000	3.2500	3.5000	3.7500	4.0000
	Min.	1.4710	1.7162	1.9632	2.2132	2.4592	2.7092	2.9592	3.2092	3.4592	3.7092	3.9592
	Tol.	0.0290	0.0338	0.0368	0.0368	0.0408	0.0408	0.0408	0.0408	0.0408	0.0408	0.0408
Class 1 minor diameter	Max.[1]	1.2911	1.4994	1.7217	1.9717	2.1869	2.4369	2.6869	2.9369	3.1869	3.4369	3.6869
Classes 2, 3, and 4, minor diameter	Max.[1]	1.2955	1.5046	1.7274	1.9774	2.1933	2.4433	2.6933	2.9433	3.1933	3.4433	3.6933
Class 1, pitch diameter	Max.	1.3873	1.6149	1.8500	2.1000	2.3312	2.5812	2.8312	3.0812	3.3312	3.5812	3.8312
	Min.	1.3728	1.5980	1.8316	2.0816	2.3108	2.5608	2.8108	3.0608	3.3108	3.5608	3.8108
	Tol.	0.0145	0.0169	0.0184	0.0184	0.0204	0.0204	0.0204	0.0204	0.0204	0.0204	0.0204
Class 2, pitch diameter	Max.	1.3917	1.6201	1.8557	2.1057	2.3376	2.5876	2.8376	3.0876	3.3376	3.5876	3.8376
	Min.	1.3816	1.6085	1.8430	2.0930	2.3236	2.5736	2.8236	3.0736	3.3236	3.5736	3.8236
	Tol.	0.0101	0.0116	0.0127	0.0127	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140

Class 3, pitch diameter	Max.	1.3917	1.6201	1.8557	2.1057	2.3376	2.5876	2.8376	3.0876	3.3376	3.5876	3.8376
	Min.	1.3846	1.6119	1.8468	2.0968	2.3279	2.5779	2.8279	3.0779	3.3279	3.5779	3.8279
	Tol.	0.0071	0.0082	0.0089	0.0089	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097
Class 4, pitch diameter	Max.	1.3926	1.6211	1.8568	2.1068	2.3389	2.5889	2.8389	3.0889	3.3389	3.5889	3.8389
	Min.	1.3890	1.6170	1.8524	2.1024	2.3341	2.5841	2.8341	3.0841	3.3341	3.5841	3.8341
	Tol.	0.0036	0.0041	0.0044	0.0044	0.0048	0.0048	0.0048	0.0048	0.0048	0.0048	0.0048
NUTS AND TAPPED HOLES												
Classes 1, 2, 3, and 4, major diameter	Min.[2]	1.5000	1.7500	2.0000	2.2500	2.5000	2.7500	3.0000	3.2500	3.5000	3.7500	4.0000
Classes 1, 2, 3, and 4, minor diameter	Max.[3]	1.3376	1.5551	1.7835	2.0335	2.2564	2.5064	2.7564	3.0064	3.2564	3.5064	3.7564
	Min.	1.3196	1.5335	1.7594	2.0094	2.2294	2.4794	2.7294	2.9794	3.2294	3.4794	3.7294
	Tol.	0.0180	0.0216	0.0241	0.0241	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270
Classes 1, 2, 3, and 4, pitch diameter	Min.	1.3917	1.6201	1.8557	2.1057	2.3376	2.5876	2.8376	3.0876	3.3376	3.5876	3.8376
Class 1, pitch diameter	Max.[4]	1.4062	1.6370	1.8741	2.1241	2.3580	2.6080	2.8580	3.1080	3.3580	3.6080	3.8580
	Tol.	0.0145	0.0169	0.0184	0.0184	0.0204	0.0204	0.0204	0.0204	0.0204	0.0204	0.0204
Class 2, pitch diameter	Max.[4]	1.4018	1.6317	1.8684	2.1184	2.3516	2.6016	2.8516	3.1016	3.3516	3.6016	3.8516
	Tol.	0.0101	0.0116	0.0127	0.0127	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140
Class 3, pitch diameter	Max.[4]	1.3988	1.6283	1.8646	2.1146	2.3473	2.5973	2.8473	3.0973	3.3473	3.5973	3.8473
	Tol.	0.0071	0.0082	0.0089	0.0089	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097
Class 4, pitch diameter	Max.[4]	1.3953	1.6242	1.8601	2.1101	2.3424	2.5924	2.8424	3.0924	3.3424	3.5924	3.8424
	Tol.	0.0036	0.0041	0.0044	0.0044	0.0048	0.0048	0.0048	0.0048	0.0048	0.0048	0.0048

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[1] Dimensions given for the maximum minor diameter of the screw are figured to the intersection of the worn tool arc with a center line through crest and root. The minimum minor diameter of the screw shall be that corresponding to a flat at the minor diameter of the minimum screw equal to $\frac{1}{8} \times p$, and may be determined by subtracting the basic thread depth, h (or $0.6495p$), from the minimum pitch diameter of the screw.

[2] Dimensions for the minimum major diameter of the nut correspond to the basic flat ($\frac{1}{8} \times p$) and the profile at the major diameter produced by a worn tool must not fall below the basic outline. The maximum major diameter of the nut shall be that corresponding to a flat at the major diameter of the maximum nut equal to $\frac{1}{24} \times p$, and may be determined by adding $1\frac{2}{9} \times h$ (or $0.7939p$) to the maximum pitch diameter of the nut.

[3] Present Army ordnance practice follows Handbook H25 and the mimeographed Supplement to Handbook H28 in the maximum minor diameters of nuts.

[4] These dimensions are the minimum metal or "not go" size. The "go" or basic size is the one that should be placed on the component drawing with the tolerance.

TABLE 4.—LIMITING DIMENSIONS AND TOLERANCES, CLASSES 1, 2, 3, AND 4 FITS, AMERICAN NATIONAL FINE-THREAD SERIES

Dimensions and Tolerances, in Inches		Machine Screw Number or Nominal Size													
		0	1	3	3	4	5	6	8	10	12	1/4	5/16	3/8	7/16
		Threads per Inch													
		80	72	64	56	48	44	40	36	32	28	28	24	24	20
BOLTS AND SCREWS															
Class 1, major diam.	Max.	0.0593	0.0723	0.0853	0.0982	0.1111	0.1241	0.1370	0.1629	0.1889	0.2148	0.2488	0.3112	0.3737	0.4360
	Min.	0.0545	0.0673	0.0801	0.0926	0.1049	0.1177	0.1302	0.1557	0.1813	0.2062	0.2402	0.3020	0.3645	0.4258
	Tol.	0.0048	0.0050	0.0052	0.0056	0.0062	0.0064	0.0068	0.0072	0.0076	0.0086	0.0086	0.0092	0.0092	0.0102
Classes 2, 3, and 4, major diam.	Max.	0.0600	0.0730	0.0860	0.0990	0.1120	0.1250	0.1380	0.1640	0.1900	0.2160	0.2500	0.3125	0.3750	0.4375
	Min.	0.0566	0.0694	0.0822	0.0950	0.1076	0.1204	0.1332	0.1590	0.1846	0.2098	0.2438	0.3059	0.3684	0.4303
	Tol.	0.0034	0.0036	0.0038	0.0040	0.0044	0.0046	0.0048	0.0050	0.0054	0.0062	0.0062	0.0066	0.0066	0.0072
Class 1, minor diam.	Max.[1]	0.0440	0.0553	0.0661	0.0763	0.0855	0.0962	0.1063	0.1288	0.1506	0.1710	0.2050	0.2601	0.3226	0.3747
Classes 2, 3, and 4, minor diam.	Max.[1]	0.0447	0.0560	0.0668	0.0771	0.0864	0.0971	0.1073	0.1299	0.1517	0.1722	0.2062	0.2614	0.3239	0.3762
Class 1, pitch diam.	Max.	0.0512	0.0633	0.0752	0.0866	0.0976	0.1093	0.1208	0.1449	0.1686	0.1916	0.2256	0.2841	0.3466	0.4035
	Min.	0.0488	0.0608	0.0726	0.0838	0.0945	0.1061	0.1174	0.1413	0.1648	0.1873	0.2213	0.2795	0.3420	0.3984
	Tol.	0.0024	0.0025	0.0026	0.0028	0.0031	0.0032	0.0034	0.0036	0.0038	0.0043	0.0043	0.0046	0.0046	0.0051
Class 2, pitch diam.	Max.	0.0519	0.0640	0.0759	0.0874	0.0985	0.1102	0.1218	0.1460	0.1697	0.1928	0.2268	0.2854	0.3479	0.4050
	Min.	0.0502	0.0622	0.0740	0.0854	0.0963	0.1079	0.1194	0.1435	0.1670	0.1897	0.2237	0.2821	0.3446	0.4014
	Tol.	0.0017	0.0018	0.0019	0.0020	0.0022	0.0023	0.0024	0.0025	0.0027	0.0031	0.0031	0.0033	0.0033	0.0036

Class 3, pitch diam.......	Max.	0.0519	0.0640	0.0759	0.0874	0.0985	0.1102	0.1218	0.1460	0.1697	0.1928	0.2268	0.2854	0.3479	0.4050
	Min.	0.0506	0.0627	0.0745	0.0859	0.0969	0.1086	0.1201	0.1442	0.1678	0.1906	0.2246	0.2830	0.3455	0.4024
	Tol.	0.0013	0.0013	0.0014	0.0015	0.0016	0.0016	0.0017	0.0018	0.0019	0.0022	0.0022	0.0024	0.0024	0.0026
Class 4, pitch diam.......	Max.	......	......	......	......	......	......	......	......	......	......	0.2270	0.2857	0.3482	0.4053
	Min.	......	......	......	......	......	......	......	......	......	......	0.2259	0.2845	0.3470	0.4040
	Tol.	......	......	......	......	......	......	......	......	......	......	0.0011	0.0012	0.0012	0.0013
NUTS AND TAPPED HOLES															
Classes 1, 2, 3, and 4, major diam........	Min.[2]	0.0600	0.0730	0.0860	0.0990	0.1120	0.1250	0.1380	0.1640	0.1900	0.2160	0.2500	0.3125	0.3750	0.4375
Classes 1, 2, 3, and 4, minor diam.......	Max.[3]	0.0514	0.0634	0.0746	0.0856	0.0960	0.1068	0.1179	0.1402	0.1624	0.1835	0.2173	0.2739	0.3364	0.3906
	Min.	0.0465	0.0580	0.0691	0.0797	0.0894	0.1004	0.1109	0.1339	0.1562	0.1773	0.2113	0.2674	0.3299	0.3834
	Tol.	0.0049	0.0054	0.0055	0.0059	0.0066	0.0064	0.0070	0.0063	0.0062	0.0062	0.0060	0.0065	0.0065	0.0072
Classes 1, 2, 3, and 4, pitch diam.	Min.	0.0519	0.0640	0.0759	0.0874	0.0985	0.1102	0.1218	0.1460	0.1697	0.1928	0.2268	0.2854	0.3479	0.4050
Class 1, pitch diam.......	Max.[4]	0.0543	0.0665	0.0785	0.0902	0.1016	0.1134	0.1252	0.1496	0.1735	0.1971	0.2311	0.2900	0.3525	0.4101
	Tol.	0.0024	0.0025	0.0026	0.0028	0.0031	0.0032	0.0034	0.0036	0.0038	0.0043	0.0043	0.0046	0.0046	0.0051
Class 2, pitch diam.......	Max.[4]	0.0536	0.0658	0.0778	0.0894	0.1007	0.1125	0.1242	0.1485	0.1724	0.1959	0.2299	0.2887	0.3512	0.4086
	Tol.	0.0017	0.0018	0.0019	0.0020	0.0022	0.0023	0.0024	0.0025	0.0027	0.0031	0.0031	0.0033	0.0033	0.0036
Class 3, pitch diam.......	Max.[4]	0.0532	0.0653	0.0773	0.0889	0.1001	0.1118	0.1235	0.1478	0.1716	0.1950	0.2290	0.2878	0.3503	0.4076
	Tol.	0.0013	0.0013	0.0014	0.0015	0.0016	0.0016	0.0017	0.0018	0.0019	0.0022	0.0022	0.0024	0.0024	0.0026
Class 4, pitch diam.......	Max.[4]	......	......	......	......	......	......	......	......	......	......	0.2279	0.2866	0.3491	0.4063
	Tol.	......	......	......	......	......	......	......	......	......	......	0.0011	0.0012	0.0012	0.0013

See footnotes at end of table.

Table 4.—Limiting Dimensions and Tolerances, Classes 1, 2, 3, and 4 Fits, American National Fine-Thread Series.—*Continued*

Dimensions and Tolerances, in Inches		Size, in Inches									
		1/2	9/16	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2
		Threads per Inch									
		20	18	18	16	14	14	12	12	12	12
Bolts and Screws											
Class 1, major diam.	Max.	0.4985	0.5609	0.6234	0.7482	0.8729	0.9979	1.1226	1.2476	1.3726	1.4976
	Min.	0.4883	0.5495	0.6120	0.7356	0.8589	0.9839	1.1068	1.2318	1.3568	1.4818
	Tol.	0.0102	0.0114	0.0114	0.0126	0.0140	0.0140	0.0158	0.0158	0.0158	0.0158
Classes 2, 3, and 4, major diam.	Max.	0.5000	0.5625	0.6250	0.7500	0.8750	1.0000	1.1250	1.2500	1.3750	1.5000
	Min.	0.4928	0.5543	0.6168	0.7410	0.8652	0.9902	1.1138	1.2388	1.3638	1.4888
	Tol.	0.0072	0.0082	0.0082	0.0090	0.0098	0.0098	0.0112	0.0112	0.0112	0.0112
Class 1, minor diam.	Max.[1]	0.4372	0.4927	0.5552	0.6715	0.7853	0.9103	1.0204	1.1454	1.2704	1.3954
Classes 2, 3, and 4, minor diam.	Max.[1]	0.4387	0.4943	0.5568	0.6733	0.7874	0.9124	1.0228	1.1478	1.2728	1.3978
Class 1, pitch diam.	Max.	0.4660	0.5248	0.5873	0.7076	0.8265	0.9515	1.0685	1.1935	1.3185	1.4435
	Min.	0.4609	0.5191	0.5816	0.7013	0.8195	0.9445	1.0606	1.1856	1.3106	1.4356
	Tol.	0.0051	0.0057	0.0057	0.0063	0.0070	0.0070	0.0079	0.0079	0.0079	0.0079
Class 2, pitch diam.	Max.	0.4675	0.5264	0.5889	0.7094	0.8286	0.9536	1.0709	1.1959	1.3209	1.4459
	Min.	0.4639	0.5223	0.5848	0.7049	0.8237	0.9487	1.0653	1.1903	1.3153	1.4403
	Tol.	0.0036	0.0041	0.0041	0.0045	0.0049	0.0049	0.0056	0.0056	0.0056	0.0056
Class 3, pitch diam.	Max.	0.4675	0.5264	0.5889	0.7094	0.8286	0.9536	1.0709	1.1959	1.3209	1.4459
	Min.	0.4649	0.5234	0.5859	0.7062	0.8250	0.9500	1.0669	1.1919	1.3169	1.4419
	Tol.	0.0026	0.0030	0.0030	0.0032	0.0036	0.0036	0.0040	0.0040	0.0040	0.0040
Class 4, pitch diam.	Max.	0.4678	0.5267	0.5892	0.7098	0.8290	0.9540	1.0714	1.1964	1.3214	1.4464
	Min.	0.4665	0.5252	0.5877	0.7082	0.8272	0.9522	1.0694	1.1944	1.3194	1.4444
	Tol.	0.0013	0.0015	0.0015	0.0016	0.0018	0.0018	0.0020	0.0020	0.0020	0.0020

TABLE 4.—LIMITING DIMENSIONS AND TOLERANCES, CLASSES 1, 2, 3, AND 4 FITS, AMERICAN NATIONAL FINE-THREAD SERIES.—*Continued*

Dimensions and Tolerances, in Inches		Size, in Inches									
		$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$
		Threads per Inch									
		20	18	18	16	14	14	12	12	12	12
NUTS AND TAPPED HOLES											
Classes 1, 2, 3, and 4, major diam.	Min.[2]	0.5000	0.5625	0.6250	0.7500	0.8750	1.0000	1.1250	1.2500	1.3750	1.5000
Classes 1, 2, 3, and 4, minor diam	Max.[3]	0.4531	0.5100	0.5725	0.6903	0.8062	0.9312	1.0438	1.1688	1.2938	1.4188
	Min.	0.4459	0.5024	0.5649	0.6823	0.7977	0.9227	1.0348	1.1598	1.2848	1.4098
	Tol.	0.0072	0.0076	0.0076	0.0080	0.0085	0.0085	0.0090	0.0090	0.0090	0.0090
Classes 1, 2, 3, and 4, pitch diam.	Min.	0.4675	0.5264	0.5889	0.7094	0.8286	0.9536	1.0709	1.1959	1.3209	1.4459
Class 1, pitch diam.	Max.[4]	0.4726	0.5321	0.5946	0.7157	0.8356	0.9606	1.0788	1.2038	1.3288	1.4538
	Tol.	0.0051	0.0057	0.0057	0.0063	0.0070	0.0070	0.0079	0.0079	0.0079	0.0079
Class 2, pitch diam.	Max.[4]	0.4711	0.5305	0.5930	0.7139	0.8335	0.9585	1.0765	1.2015	1.3265	1.4515
	Tol.	0.0036	0.0041	0.0041	0.0045	0.0049	0.0049	0.0056	0.0056	0.0056	0.0056
Class 3, pitch diam.	Max.[4]	0.4701	0.5294	0.5919	0.7126	0.8322	0.9572	1.0749	1.1999	1.3249	1.4499
	Tol.	0.0026	0.0030	0.0030	0.0032	0.0036	0.0036	0.0040	0.0040	0.0040	0.0040
Class 4 pitch diam.	Max.[4]	0.4688	0.5279	0.5904	0.7110	0.8304	0.9554	1.0729	1.1979	1.3229	1.4479
	Tol.	0.0013	0.0015	0.0015	0.0016	0.0018	0.0018	0.0020	0.0020	0.0020	0.0020

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[1] Dimensions given for the maximum minor diameter of the screw are figured to the intersection of the worn tool arc with a center line through crest and root. The minimum minor diameter of the screw shall be that corresponding to a flat at the minor diameter of the minimum screw equal to $\frac{1}{8} \times p$, and may be determined by subtracting the basic thread depth, h (or $0.6495p$), from the minimum pitch diameter of the screw.

[2] Dimensions for the minimum major diameter of the nut correspond to the basic flat ($\frac{1}{8} \times p$) and the profile at the major diameter produced by a worn tool must not fall below the basic outline. The maximum major diameter of the nut shall be that corresponding to a flat at the major diameter of the maximum nut equal to $\frac{1}{24} \times p$, and may be determined by adding $1\frac{2}{9} \times h$ (or $0.7939p$) to the maximum pitch diameter of the nut.

[3] Present Army ordnance practice follows Handbook H25 and the mimeographed Supplement to Handbook H28 in the maximum minor diameters of nuts.

[4] These dimensions are the minimum metal or "not go" size. The "go" or basic size is the one that should be placed on the component drawing with the tolerance.

Special Pitch and Diameter Combinations.—In general, the tables given are intended for use with the two standard thread series only. The application of fine pitches to large diameters involves questions of workmanship which affect the grade of fit chosen.

When a pitch of thread is used with a diameter not called for in a standard thread series, it shall be defined as of "American National Form," but not as "American Standard."

General Specifications

The following general specifications will apply to all classes of fits specified in the body of the report. For special specifications applying to the loose fit class see the Commission's Report.

Uniform Minimum Nut.—The pitch diameter of the minimum threaded hole or nut corresponds to the basic size, variations being permitted above the basic size. The major and minor diameters of the minimum nut are also uniform for all classes of fit.

Uniform Tap Drill Sizes.—The maximum and minimum minor diameters and the consequent minor diameter tolerances are the same for all nuts of a given size for all classes of fit. This permits uniform tap drill sizes for all classes of fit.

Uniform Major and Minor Diameter of Screws.—The maximum and minimum major and minor diameters are the same for all screws of a given size for all classes of fit herein tabulated.

Length of Engagement.—The tolerances herein determined are based on a length of engagement not to exceed the nominal or major diameter of the screw. Where greater lengths of engagement are required, a corresponding increase in the accuracy of lead and thread form is necessary, which may be obtained by the provision of selection of more accurate threading tools, and the use of longer "go" gages.

Pitch-Diameter Tolerances Include Lead and Angle Variations.—The relations between these quantities are expressed by columns 4 and 5 of Tables 2, 3, 4 and 5 and are explained by the note at the bottom of each table (see page 9).

These relations may be automatically insured by using a "go" gage of the length of engagement required, or by projecting an equivalent length of thread on a suitable chart, or by so projecting a single thread constrained for the required length of engagement, or by any other means which preserves the mathematical relation between variations in pitch diameter, lead, and form.

Pitch-Diameter Tolerances on Screw Same as on Nut.—The pitch-diameter tolerances provided for a screw of a given class of fit will be the same as the pitch-diameter tolerances provided for the corresponding nut of the same class of fit.

Tolerances on Major Diameter of Screw Twice Pitch Diameter of Tolerances for Free Fit.—The allowable tolerances on the major diameter of screws of all classifications will be twice the tolerance value allowed on the pitch diameters of screws of the Free Fit (Class 2).

Tolerances on Minor Diameter of Screw.—The minimum minor diameter of a screw of a given pitch will be such as to result in a basic flat ($\frac{1}{8} \times p$) at the root.

The maximum minor diameter is that which would result from the use of a threading tool, set at the maximum pitch diameter, whose point has been worn or ground back from the basic outline by an amount equal to one-eighteenth of the basic depth of engagement ($\frac{1}{18}\ h$ or $0.03684\ p$). It is permissible that the resulting root line shall be rounded. In no case, however, should the form be such as to cause the screw to be rejected on the minor diameter by a "go" ring gage, the minor diameter of which is equal to the minimum minor diameter of the nut.

Tolerances on Major Diameter of Nut.—The maximum major diameter of the nut of a given pitch will be such as to result in a flat one-third of the basic flat ($\frac{1}{24} \times p$).

The nominal minimum major diameter of the nut equals the basic major diameter. In practice a clearance is provided to facilitate manufacture by permitting a slight rounding or wear at the crest of the tap. In no case, however, should the outline resulting from a worn tap or cutting tool be such as to cause the nut to be rejected on the major diameter by a "go" plug gage made to basic form and dimensions at the crest.

Tolerances on Minor Diameter of Nut.—The tolerances on minor diameter of a nut of a given pitch will be one-sixth of the basic thread depth regardless of the class of fit being produced ($\frac{1}{6}\ h$ or $0.10825\ p$). The maximum and minimum minor diameters are determined by the conditions set forth on page 4. In the case of a punched hole the average diameter of the hole shall govern.

Coarse-Thread Series

The American Standard Coarse-Thread Series, defined in Table 6, is recommended for use with free-fit (Class 2) tolerances, and medium-fit tolerances (Class 3). Its use with close-fit (Class 4) tolerances is also permissible, especially in producing the medium fit as described on page 4. It is recommended for use with the loose-fit tolerances (Class 1), for nuts only in the numbered sizes.

The resulting dimensions of external and internal screw threads with these fits are shown in Tables 7 to 13.

The tables in this section have been rearranged by the National Screw Thread Commission. Some of these combine data that were originally given in separate tables.

Tables 3 to 10, for example, give the limiting dimensions and tolerances of the different classes of fits for both coarse and fine threads, combined so as to avoid the necessity of consulting separate tables for bolts, screws and nuts.

Tables are also given for the 8-, 12- and 16-pitch series of threads which are being used in some industries, where the pitch of the thread is kept the same for all diameters.

Derivation of Tolerances

Net Pitch-Diameter Tolerance.—The net pitch-diameter tolerances for the several classes or grades are based on selections from a tolerance series for a pitch of $\frac{1}{20}$ inch, increasing by increments of 0.0005 inch as follows:

Grade	Tolerance	Grade	Tolerance
A	0.0005 in.	F	0.0030 in.
B	0.0010 in.	G	0.0035 in.
C	0.0015 in.	H	0.0040 in.
D	0.0020 in.	I	0.0045 in.
E	0.0025 in.	J	0.0050 in.

The grades selected are:

For loose fit	I
For free fit	F
For medium fit	D
For close fit	B

Pitch-diameter tolerances for pitches finer than $\frac{1}{20}$ inch are to each other and to the tolerance for $\frac{1}{20}$ inch as the six-tenths power of their respective pitches.

Pitch-diameter tolerances for pitches coarser than $\frac{1}{20}$ inch are to each other and to the tolerance for $\frac{1}{20}$ inch as the nine-tenths power of their respective pitches.

The factor 0.6 was chosen for pitches finer than $\frac{1}{20}$ inch because resulting tolerances except in two instances do not vary more than 0.0001 inch from the pitch-diameter tolerance in the A.S.M.E. Machine Screw Standard.

Extreme Pitch-Diameter Tolerance.—To obtain the extreme pitch-diameter tolerance there is added to the net tolerance a "gage increment" obtained as follows:

To secure extreme tolerances, add to net tolerances:

Diameter tolerance—"go" gage.

Diametrical equivalent of lead tolerance—"go" gage.

Diametrical equivalent of angle tolerance—"go" gage.
Diameter tolerance—"not go" gage.
Then subtract the following:
Diametrical equivalent of angle tolerance—"not go" gage.
½ diametrical equivalent of lead tolerance—"not go" gage.

For instance, using the tolerances (as set by the National Screw Thread Commission) for a 20-pitch gage, according to this rule the net tolerance would be increased by:

	Inches
Diameter tolerance—"go"	0.0002
Equivalent lead tolerance—"go"	0.00034
Equivalent angle tolerance—"go"	0.0002
Diameter tolerance—"not go"	0.0002
Total	0.00094

and would be decreased by:

	Inches
Equivalent angle tolerance—"not go"	0.0002
½ lead tolerance—"not go"	0.00017
Total	0.00037

Total increase, $0.00094 - 0.00037 = 0.00057$

Relation of Lead and Angle Errors to Pitch-Diameter Tolerances

Effect of Lead Error on Pitch-Diameter Tolerance.—The tolerances specified for pitch diameters include all errors of pitch and angle. Column 4 of Tables 2, 3, 4, and 5 gives the amount of lead error which absorbs one-half of the specified pitch-diameter tolerance. Lead error $\times$ 1.732 = equivalent pitch-diameter error.

Effect of Angle Error on Pitch-Diameter Tolerance.—Column 5 of the above-mentioned tables gives the variation in the half angle of thread which absorbs one-half of the specified pitch-diameter tolerance.

The formula giving the relation between the amount of pitch-diameter tolerance E' absorbed by a variation of a' in half-angle of thread is, for symmetrical threads.

$$\cot a' = \frac{h}{E' \sin a \cos a} \pm \cot a$$

where h = depth of thread.
a = half-angle of thread.
a' = error in half-angle.

The sign of $\cot a$ is plus when the half-angle of thread is less than the basic by a' and minus when the half-angle is greater than basic. The approximate mean values for a' and E' will be obtained when plus or minus $\cot a$ is omitted from the above formula. For American (National) form of screw thread, the depth of thread

$$h = \tfrac{3}{8}p \cot 30^\circ \text{ and } a = 30^\circ.$$

Substituting, the formula becomes

$$\cot a' = \frac{3p}{2E'}$$

or
$$E' = \frac{3p}{2} \times \tan a' = 1.5\,p \tan a'.$$

For all practical purposes, the equivalent pitch-diameter corrections for any angular error can be taken as proportional to the values given in the above tables. For example, on the $\frac{5}{16}$–18 thread, an angular error 1 degree 25 minutes is equivalent to a pitch-diameter error of 0.00206 inch. An angular error of 17 minutes or one-fifth the amount given in the table is equivalent to 0.00041 inch, which is almost directly proportional.

Tolerances for Loose Fit (Class 1)

This fit is recommended whenever an *allowance* is required between the maximum screw and the minimum nut, and in the cases where larger tolerances than those given by the free fit (Class 2) are needed.

This class of screw threads will be defined and specified as follows:

Minimum nut is basic.

Maximum screw is below basic.

The major diameter and pitch diameter of the maximum screw will be below basic in accordance with the diameter specified in Tables 18 and 20.

Direction of tolerance on the nut: The tolerance on the nut will be plus.

Direction of tolerance on the screw: The tolerance on the screw will be minus.

Tolerance values: The tolerances on a screw or nut of given diameter and pitch will be such as to result from the dimensions given in Tables 18, 19, 20 and 21.

Truncated Thread Gages

The thread form of a ring-thread gage becomes worn with use. This wear on the flank of the thread may be largely from near the pitch line to the minor diameter, the thread near the major diameter of the ring being worn very little.

When such a worn ring gage is tested or set on a full form-setting plug, the unworn area near the major diameter gives a fictitious setting, and a ring that appears to be correct may be much oversize at pitch diameter.

Such a worn "go" ring gage, when set to a correct full form-setting plug, would pass screws that were oversize on pitch diameter. Therefore, setting plugs for "go" ring gages should be truncated to near the pitch line.

TABLE 5.—AMERICAN NATIONAL EXTRA-FINE-THREAD SERIES

Identification		Basic Diameters			Thread Data						
Size, in Inches	Threads per Inch,	Major Diameter, D, in Inches	Pitch Diameter, E, in Inches	Minor Diameter, K, in Inches	Metric Equivalent of Major Diameter, in Millimeters	Pitch, p, in Inches	Depth of Thread, h, in Inches	Basic Width of Flat, $\frac{p}{8}$, in Inches	Minimum Width of Flat at Major Diameter of Nut, $\frac{p}{24}$, in Inches	Helix Angle of Basic Pitch Diameter, s	Basic Area of Section at Root of Thread, $\frac{\pi K^2}{4}$, in Square Inches
										Deg. Min.	
$\frac{1}{4}$	32	0.2500	0.2297	0.2094	6.350	0.03125	0.02030	0.00391	0.00130	2 29	0.0344
$\frac{5}{16}$	32	0.3125	0.2922	0.2719	7.938	0.03125	0.02030	0.00391	0.00130	1 57	0.0581
$\frac{3}{8}$	32	0.3750	0.3547	0.3344	9.525	0.03125	0.02030	0.00391	0.00130	1 36	0.0878
$\frac{7}{16}$	28	0.4375	0.4143	0.3911	11.113	0.03571	0.02320	0.00446	0.00149	1 34	0.1201
$\frac{1}{2}$	28	0.5000	0.4768	0.4536	12.700	0.03571	0.02320	0.00446	0.00149	1 22	0.1616
$\frac{9}{16}$	24	0.5625	0.5354	0.5084	14.288	0.04167	0.02706	0.00521	0.00174	1 25	0.2030
$\frac{5}{8}$	24	0.6250	0.5979	0.5709	15.875	0.04167	0.02706	0.00521	0.00174	1 16	0.2560
$\frac{11}{16}$	24	0.6875	0.6604	0.6334	17.463	0.04167	0.02706	0.00521	0.00174	1 9	0.3151
$\frac{3}{4}$	20	0.7500	0.7175	0.6850	19.050	0.05000	0.03248	0.00625	0.00208	1 16	0.3685
$\frac{13}{16}$	20	0.8125	0.7800	0.7475	20.638	0.05000	0.03248	0.00625	0.00208	1 10	0.4388
$\frac{7}{8}$	20	0.8750	0.8425	0.8100	22.225	0.05000	0.03248	0.00625	0.00208	1 4	0.5153
$\frac{15}{16}$	20	0.9375	0.9050	0.8725	23.813	0.05000	0.03248	0.00625	0.00208	1 0	0.5979
1	20	1.0000	0.9675	0.9350	25.400	0.05000	0.03248	0.00625	0.00208	0 57	0.6866
1 $\frac{1}{16}$	18	1.0625	1.0264	0.9903	26.988	0.05556	0.03608	0.00694	0.00231	0 59	0.7702
1$\frac{1}{8}$	18	1.1250	1.0889	1.0528	28.575	0.05556	0.03608	0.00694	0.00231	0 56	0.8705
1 $\frac{3}{16}$	18	1.1875	1.1514	1.1153	30.163	0.05556	0.03608	0.00694	0.00231	0 53	0.9770
1$\frac{1}{4}$	18	1.2500	1.2139	1.1778	31.750	0.05556	0.03608	0.00694	0.00231	0 50	1.0895
1 $\frac{5}{16}$	18	1.3125	1.2764	1.2403	33.338	0.05556	0.03608	0.00694	0.00231	0 48	1.2082
1$\frac{3}{8}$	18	1.3750	1.3389	1.3028	34.925	0.05556	0.03608	0.00694	0.00231	0 45	1.3330
1 $\frac{7}{16}$	18	1.4375	1.4014	1.3653	36.513	0.05556	0.03608	0.00694	0.00231	0 43	1.4640
1$\frac{1}{2}$	18	1.5000	1.4639	1.4278	38.100	0.05556	0.03608	0.00694	0.00231	0 42	1.6011
1 $\frac{9}{16}$	18	1.5625	1.5264	1.4903	39.688	0.05556	0.03608	0.00694	0.00231	0 40	1.7444
1$\frac{5}{8}$	18	1.6250	1.5889	1.5528	41.275	0.05556	0.03608	0.00694	0.00231	0 38	1.8937
1 $\frac{11}{16}$	18	1.6875	1.6514	1.6153	42.863	0.05556	0.03608	0.00694	0.00231	0 37	2.0493
1$\frac{3}{4}$	16	1.7500	1.7094	1.6688	44.450	0.06250	0.04059	0.00781	0.00260	0 40	2.1873
2	16	2.0000	1.9594	1.9188	50.800	0.06250	0.04059	0.00781	0.00260	0 35	2.8917

TABLE 6.—LIMITING DIMENSIONS AND TOLERANCES, CLASSES 2 AND 3 FITS, AMERICAN NATIONAL EXTRA-FINE THREAD SERIES

Dimensions and Tolerances,[1] in Inches		Size, in Inches—Threads per Inch												
		$\frac{1}{4}$–32	$\frac{5}{16}$–32	$\frac{3}{8}$–32	$\frac{7}{16}$–28	$\frac{1}{2}$–28	$\frac{9}{16}$–24	$\frac{5}{8}$–24	$\frac{11}{16}$–24	$\frac{3}{4}$–20	$\frac{13}{16}$–20	$\frac{7}{8}$–20	$\frac{15}{16}$–20	1–20
BOLTS AND SCREWS														
Classes 2 and 3, major diameter..........	Max.	0.2500	0.3125	0.3750	0.4375	0.5000	0.5625	0.6250	0.6875	0.7500	0.8125	0.8750	0.9375	1.0000
	Min.	0.2446	0.3071	0.3696	0.4313	0.4938	0.5559	0.6184	0.6809	0.7428	0.8053	0.8678	0.9303	0.9928
	Tol.	0.0054	0.0054	0.0054	0.0062	0.0062	0.0066	0.0066	0.0066	0.0072	0.0072	0.0072	0.0072	0.0072
Classes 2 and 3, minor diameter..............	Max.[2]	0.2117	0.2742	0.3367	0.3937	0.4562	0.5114	0.5739	0.6364	0.6887	0.7512	0.8137	0.8762	0.9387
Class 2, pitch diameter	Max.	0.2297	0.2922	0.3547	0.4143	0.4768	0.5354	0.5979	0.6604	0.7175	0.7800	0.8425	0.9050	0.9675
	Min.[4]	0.2265	0.2889	0.3513	0.4107	0.4731	0.5314	0.5938	0.6563	0.7129	0.7754	0.8378	0.9003	0.9627
	Tol.	0.0032	0.0033	0.0034	0.0036	0.0037	0.0040	0.0041	0.0041	0.0046	0.0046	0.0047	0.0047	0.0048
Class 3, pitch diameter	Max.	0.2297	0.2922	0.3547	0.4143	0.4768	0.5354	0.5979	0.6604	0.7175	0.7800	0.8425	0.9050	0.9675
	Min.[4]	0.2275	0 2899	0.3523	0.4118	0.4742	0.5326	0.5950	0.6575	0.7143	0.7768	0.8392	0.9017	0.9641
	Tol.	0.0022	0.0023	0.0024	0.0025	0.0026	0.0028	0.0029	0.0029	0.0032	0.0032	0.0033	0.0033	0.0034
NUTS AND TAPPED HOLES														
Classes 2 and 3, major diameter..............	Min.[3]	0.2500	0.3125	0.3750	.04375	0.5000	0.5625	0.6250	0.6875	0.7500	0.8125	0.8750	0.9370	1.0000
Classes 2 and 3, minor diameter..........	Min.	0.2162	0.2787	0.3412	0.3988	0.4613	0.5174	0.5799	0.6424	0.6959	0.7584	0.8209	0.8834	0.9459
	Max.	0.2208	0.2833	0.3458	0.4041	0.4666	0.5235	0.5860	.06485	0.7027	0.7652	0.8277	0.8902	0.9527
	Tol.	0.0046	0.0046	0.0046	0.0053	0.0053	0.0061	0.0061	0.0061	0.0068	0.0068	0.0068	0.0068	0.0068
Class 2, pitch diameter	Min.	0.2297	0.2922	0.3547	0.4143	0.4768	0.5354	0.5979	0.6604	0.7175	0.7800	0.8425	0.9050	0.9675
	Max.[4]	0.2329	0.2955	0.3581	0.4179	0.4805	0.5394	0.6020	0.6645	0.7221	0.7846	0.8472	0.9097	0.9723
	Tol.	0.0032	0.0033	0.0034	0.0036	0.0037	0.0040	0.0041	0.0041	0.0046	0.0046	0.0047	0.0047	0.0048
Class 3, pitch diameter	Min.	0.2297	0.2922	0.3547	0.4143	0.4768	0.5354	0.5979	0.6604	0.7175	0.7800	0.8425	0.9050	0.9675
	Max.[4]	0.2319	0.2945	0.3571	0.4168	0.4794	0.5382	0.6008	0.6633	0.7207	0.7832	0.8458	0.9083	0.9709
	Tol.	0.0022	0.0023	0.0024	0.0025	0.0026	0.0028	0.0029	0.0029	0.0032	0.0032	0.0033	0.0033	0.0034

		Size, in Inches—Threads per Inch												
		$1\frac{1}{16}$–18	$1\frac{1}{8}$–18	$1\frac{3}{16}$–18	$1\frac{1}{4}$–18	$1\frac{5}{16}$–18	$1\frac{3}{8}$–18	$1\frac{7}{16}$–18	$1\frac{1}{2}$–18	$1\frac{9}{16}$–18	$1\frac{5}{8}$–18	$1\frac{11}{16}$–18	$1\frac{3}{4}$–16	2–16
BOLTS AND SCREWS														
Classes 2 and 3, major diameter...........	Max.	1.0625	1.1250	1.1875	1.2500	1.3125	1.3750	1.4375	1.5000	1.5625	1.6250	1.6875	1.7500	2.0000
	Min.	1.0543	1.1168	1.1793	1.2418	1.3043	1.3668	1.4293	1.4918	1.5543	1.6168	1.6793	1.7410	1.9910
	Tol.	0.0082	0.0082	0.0082	0.0082	0.0082	0.0082	0.0082	0.0082	0.0082	0.0082	0.0082	0.0090	0.0090
Classes 2 and 3, minor diameter..............	Max.[2]	0.9943	1.0568	1.1193	1.1818	1.2443	1.3068	1.3693	1.4318	1.4943	1.5568	1.6193	1.6733	1.9233
Class 2, pitch diameter	Max.	1.0264	1.0889	1.1514	1.2139	1.2764	1.3389	1.4014	1.4639	1.5264	1.5889	1.6514	1.7094	1.9594
	Min.[4]	1.0216	1.0837	1.1462	1.2086	1.2711	1.3335	1.3960	1.4584	1.5209	1.5833	1.6458	1.7035	1.9533
	Tol.	0.0048	0.0052	0.0052	0.0053	0.0053	0.0054	0.0054	0.0055	0.0055	0.0056	0.0056	0.0059	0.0061
Class 3, pitch diameter	Max.	1.0264	1.0889	1.1514	1.2139	1.2764	1.3389	1.4014	1.4639	1.5264	1.5889	1.6514	1.7094	1.9594
	Min.[4]	1.0228	1.0853	1.1478	1.2102	1.2727	1.3351	1.3976	1.4601	1.5225	1.5850	1.6475	1.7053	1.9551
	Tol.	0.0036	0.0036	0.0036	0.0037	0.0037	0.0038	0.0038	0.0038	0.0039	0.0039	0.0039	0.0041	0.0043
NUTS AND TAPPED HOLES														
Classes 2 and 3, major diameter..............	Min.[3]	1.0625	1.1250	1.1875	1.2500	1.3125	1.3750	1.4375	1.5000	1.5625	1.6250	1.6875	1.7500	2.0000
Classes 2 and 3, minor diameter...........	Min.	1.0024	1.0649	1.1274	1.1899	1.2524	1.3149	1.3774	1.4399	1.5024	1.5649	1.6274	1.6823	1.9323
	Max.	1.0099	1.0724	1.1349	1.1974	1.2599	1.3224	1.3849	1.4474	1.5099	1.5724	1.6349	1.6903	1.9403
	Tol.	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0080	0.0080
Class 2, pitch diameter	Min.	1.0264	1.0889	1.1514	1.2139	1.2764	1.3389	1.4014	1.4639	1.5264	1.5889	1.6514	1.7094	1.9594
	Max.[4]	1.0312	1.0941	1.1566	1.2192	1.2817	1.3443	1.4068	1.4694	1.5319	1.5945	1.6570	1.7153	1.9655
	Tol.	0.0048	0.0052	0.0052	0.0053	0.0053	0.0054	0.0054	0.0055	0.0055	0.0056	0.0056	0.0059	0.0061
Class 3, pitch diameter	Min.	1.0264	1.0889	1.1514	1.2139	1.2764	1.3389	1.4014	1.4639	1.5264	1.5889	1.6514	1.7094	1.9594
	Max.[4]	1.0300	1.0925	1.1550	1.2176	1.2801	1.3427	1.4052	1.4677	1.5303	1.5928	1.6553	1.7135	1.9637
	Tol.	0.0036	0.0036	0.0036	0.0037	0.0037	0.0038	0.0038	0.0038	0.0039	0.0039	0.0039	0.0041	0.0043

[1] Pitch diameter tolerances include errors of lead and angle. The class 2 tolerances are based on the formulas in table 116 and a length of engagement of 6 threads. The class 3 tolerances are 70 per cent of the class 2 tolerances.

[2] Dimensions given for the maximum minor diameter of the screw are figured to the intersection of the worn tool arc with a center line through crest and root. The minimum minor diameter of the screw shall be that corresponding to a flat at the minor diameter of the minimum screw equal to $\frac{1}{8} \times p$, and may be determined by subtracting the basic thread depth, h (or $0.6495p$), from the minimum pitch diameter of the screw.

[3] Dimensions for the minimum major diameter of the nut correspond to the basic flat ($\frac{1}{8} \times p$), and the profile at the major diameter produced by a worn tool must not fall below the basic outline. The maximum major diameter of the nut shall be that corresponding to a flat at the major diameter of the maximum nut equal to $\frac{1}{24} \times p$, and may be determined by adding $1\frac{2}{9} \times h$ (or $0.7939p$) to the maximum pitch diameter of the nut.

[4] These dimensions are the minimum metal or "not go" size. The "go" or basic size is the one that should be placed on the component drawing with the tolerance.

TABLE 7.—AMERICAN NATIONAL 8-PITCH THREAD SERIES

Pitch, p = 0.12500 Inch; Depth of Thread, h = 0.08119 Inch; Basic Width of Flat, $\frac{p}{8}$ = 0.01562 Inch; Minimum Width of Flat at Major Diameter of Nut, $\frac{p}{24}$ = 0.00521 Inch

Identification	Basic Diameters			Thread Data			
Size, in Inches	Major Diameter, D, in Inches	Pitch Diameter, E, in Inches	Minor Diameter, K, in Inches	Metric Equivalent of Major Diameter, in Millimeters	Helix Angle at Basic Pitch Diameter, s		Basic Area of Section at Root of Thread, $\frac{\pi K^2}{4}$, Square Inches
					Deg	Min	
1[1]	1.0000	0.9188	0.8376	25.400	2	29	0.5510
1⅛	1.1250	1.0438	0.9626	28.575	2	11	0.7277
1¼	1.2500	1.1688	1.0876	31.750	1	57	0.9290
1⅜	1.3750	1.2938	1.2126	34.925	1	46	1.1548
1½	1.5000	1.4188	1.3376	38.100	1	36	1.4052
1⅝	1.6250	1.5438	1.4626	41.275	1	29	1.6801
1¾	1.7500	1.6688	1.5876	44.450	1	22	1.9796
1⅞	1.8750	1.7938	1.7126	47.625	1	16	2.3036
2	2.0000	1.9188	1.8376	50.800	1	11	2.6521
2⅛	2.1250	2.0438	1.9626	53.975	1	7	3.0252
2¼	2.2500	2.1688	2.0876	57.150	1	3	3.4228
2½	2.5000	2.4188	2.3376	63.500	0	57	4.2917
2¾	2.7500	2.6688	2.5876	69.850	0	51	5.2588
3	3.0000	2.9188	2.8376	76.200	0	47	6.3240
3¼	3.2500	3.1688	3.0876	82.550	0	43	7.4874
3½	3.5000	3.4188	3.3376	88.900	0	49	8.7490
3¾	3.7500	3.6688	3.5876	95.250	0	37	10.1088
4	4.0000	3.9188	3.8376	101.600	0	35	11.5667
4¼	4.2500	4.1688	4.0876	107.950	0	33	13.1228
4½	4.5000	4.4188	4.3376	114.300	0	31	14.7771
4¾	4.7500	4.6688	4.5876	120.650	0	29	16.5295
5	5.0000	4.9188	4.8376	127.000	0	28	18.3802
5¼	5.2500	5.1688	5.0876	133.350	0	26	20.3290
5½	5.5000	5.4188	5.3376	139.700	0	25	22.3760
5¾	5.7500	5.6688	5.5876	146.050	0	24	24.5211
6	6.0000	5.9188	5.8376	152.400	0	23	26.7645

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[1] Standard size of the American National coarse-thread series.

TABLE 8.—AMERICAN NATIONAL 12-PITCH THREAD SERIES

Pitch, $p = 0.08333$ Inch; Depth of Thread, $h = 0.05413$ Inch; Basic Width of Flat, $\frac{p}{8} = 0.01042$ Inch; Minimum Width of Flat at Major Diameter of Nut, $\frac{p}{24} = 0.00347$ Inch

Identification	Basic Diameters			Thread Data			
Size, in Inches	Major Diameter, D, in Inches	Pitch Diameter, E, in Inches	Minor Diameter, K, in Inches	Metric Equivalent of Major Diameter, in Millimeters	Helix Angle at Basic Pitch Diameter, s		Basic Area of Section at Root of Thread, $\frac{\pi K^2}{4}$, Square Inches
					Deg	Min	
1/2	0.5000	0.4459	0.3917	12.700	3	24	0.1205
9/16[1]	0.5625	0.5084	0.4542	14.288	2	59	0.1620
5/8	0.6250	0.5709	0.5167	15.875	2	40	0.2097
11/16	0.6875	0.6334	0.5792	17.463	2	24	0.2635
3/4	0.7500	0.6959	0.6417	19.050	2	11	0.3234
13/16	0.8125	0.7584	0.7042	20.638	2	0	0.3895
7/8	0.8750	0.8209	0.7667	22.225	1	51	0.4617
15/16	0.9375	0.8834	0.8292	23.813	1	43	0.5400
1	1.0000	0.9459	0.8917	25.400	1	36	0.6245
1 1/16	1.0625	1.0084	0.9542	26.988	1	30	0.7151
1 1/8[2]	1.1250	1.0709	1.0167	28.575	1	25	0.8118
1 3/16	1.1875	1.1334	1.0792	30.163	1	20	0.9147
1 1/4[2]	1.2500	1.1959	1.1417	31.750	1	16	1.0237
1 5/16	1.3125	1.2584	1.2042	33.338	1	12	1.1389
1 3/8[2]	1.3750	1.3209	1.2667	34.925	1	9	1.2602
1 7/16	1.4375	1.3834	1.3292	36.513	1	6	1.3876
1 1/2[2]	1.5000	1.4459	1.3917	38.100	1	3	1.5212
1 5/8	1.6250	1.5709	1.5167	41.275	0	58	1.8067
1 3/4	1.7500	1.6959	1.6417	44.450	0	54	2.1168
1 7/8	1.8750	1.8209	1.7667	47.625	0	50	2.4514
2	2.0000	1.9459	1.8917	50.800	0	47	2.8106
2 1/4	2.2500	2.1959	2.1417	57.150	0	42	3.6025
2 1/2	2.5000	2.4459	2.3917	63.500	0	37	4.4927
2 3/4	2.7500	2.6959	2.6417	69.850	0	34	5.4810
3	3.0000	2.9459	2.8917	76.200	0	31	6.5674
3 1/4	3.2500	3.1959	3.1417	82.550	0	29	7.7521
3 1/2	3.5000	3.4459	3.3917	88.900	0	26	9.0349
3 3/4	3.7500	3.6959	3.6417	95.250	0	25	10.4159
4	4.0000	3.9459	3.8917	101.600	0	23	11.8951
4 1/4	4.2500	4.1950	4.1417	107.950	0	22	13.4725
4 1/2	4.5000	4.4459	4.3917	114.300	0	21	15.1480
4 3/4	4.7500	4.6959	4.6417	120.650	0	19	16.9217
5	5.0000	4.9459	4.8917	127.000	0	18	18.7936
5 1/4	5.2500	5.1959	5.1417	133.350	0	18	20.7636
5 1/2	5.5000	5.4459	5.3917	139.700	0	17	22.8319
5 3/4	5.7500	5.6959	5.6417	146.050	0	16	24.9983
6	6.0000	5.9459	5.8917	152.400	0	15	27.2628

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[1] Standard size of the American National coarse-thread series.
[2] Standard size of the American National fine-thread series.

UNIFORM PITCH SCREW THREADS FOR HIGH-PRESSURE FASTENINGS, BOILER APPLICATIONS, AND MACHINE COMPONENTS

Where special threads are required, it is advisable to select a suitable pitch as standard for a given range of sizes. It is advantageous to have a uniform use of such special threads and pitches of 8, 12, and 16 threads per inch have been selected and are widely used.

The 8-Pitch Standard

This is used largely for bolts in high-pressure pipe flanges, in cylinder-head studs, and in similar fastenings where an initial tension is required in the fastening, so that the joint will not open up when pressure is applied. For this reason it is not advisable to have the pitch increase with the diameter, and the 8-pitch thread is widely used.

The 12-Pitch Standard

The 12-pitch threads are largely used in sizes from 1 inch to $1\frac{3}{4}$ inches in boiler practice, for this requires the retapping of worn stud holes to the next larger size, in increments of $\frac{1}{16}$ inch. This holds through most of the range. The 12-pitch threads are also widely used in machine construction on such parts as thin nuts for shafts and sleeves. Shoulder diameters are usually limited to $\frac{1}{8}$-inch steps, and the 12-pitch thread is the coarsest that will permit a threaded collar which screws on a threaded shoulder to slip over a shaft $\frac{1}{8}$ inch smaller in diameter.

The 16-Pitch Standard

While this thread is intended primarily for such work as adjusting collars, which require a fine thread, it also has other uses. It is used in retaining nuts for bearings and similar places.

TABLE 9.—TOLERANCE INCREMENTS FOR SPECIAL THREADS

Class of Fit	Diameter Increment	Length of Engagement	Pitch Increment
1	$0.002\sqrt{D}$	$0.002Q$	$0.020\sqrt{p}$
2	$0.002\sqrt{D}$	$0.002Q$	$0.010\sqrt{p}$
3	$0.002\sqrt{D}$	$0.002Q$	$0.005\sqrt{p}$
4	$0.001\sqrt{D}$	$0.001Q$	$0.0025\sqrt{p}$

Q is the symbol for length of engagement. For the 8-, 12-, and 16-pitch thread series, and the Extra-Fine thread series, the Class 3 tolerances are 70 per cent of Class 2 tolerances as derived from these formulas.

TABLE 9*a*.—AMERICAN NATIONAL 16-PITCH THREAD SERIES

[Pitch, p = 0.06250 Inch; Depth of Thread, h = 0.4059 Inch; Basic Width of Flat, $\frac{p}{8}$ = 0.00781 Inch; Minimum Width of Flat at Major Diameter of Nut, $\frac{p}{24}$ = 0.00260 Inch]

Identification	Basic Diameters			Thread Data			
Size, in Inches	Major Diameter, D, in inches	Pitch Diameter, E, in Inches	Minor Diameter, K, in Inches	Metric Equivalent of Major Diameter, in Millimeters	Helix Angle at Basic Pitch Diameter, s		Basic Area of Section at Root of Thread, $\frac{\pi K^2}{4}$, Square Inches
					Deg	Min	
3/4	0.7500	0.7094	0.6688	19.050	1	36	0.3513
13/16	0.8125	0.7719	0.7313	20.638	1	29	0.4200
7/8	0.8750	0.8344	0.7938	22.225	1	22	0.4949
15/16	0.9375	0.8969	0.8563	23.813	1	16	0.5759
1	1.0000	0.9594	0.9188	25.400	1	11	0.6630
1 1/16	1.0625	1.0219	0.9813	26.988	1	7	0.7563
1 1/8	1.1250	1.0844	1.0438	28.575	1	3	0.8557
1 3/16	1.1875	1.1469	1.1063	30.163	1	0	0.9612
1 1/4	1.2500	1.2094	1.1688	31.750	0	57	1.0729
1 5/16	1.3125	1.2719	1.2313	33.338	0	54	1.1907
1 3/8	1.3750	1.3344	1.2938	34.925	0	51	1.3147
1 7/16	1.4375	1.3969	1.3563	36.513	0	49	1.4448
1 1/2	1.5000	1.4594	1.4188	38.100	0	47	1.5810
1 9/16	1.5625	1.5219	1.4813	39.688	0	45	1.7234
1 5/8	1.6250	1.5844	1.5438	41.275	0	43	1.8719
1 11/16	1.6875	1.6469	1.6063	42.863	0	42	2.0265
1 3/4	1.7500	1.7094	1.6688	44.450	0	40	2.1873
1 13/16	1.8125	1.7719	1.7313	46.038	0	39	2.3542
1 7/8	1.8750	1.8344	1.7938	47.625	0	37	2.5272
1 15/16	1.9375	1.8969	1.8563	49.213	0	36	2.7064
2	2.0000	1.9594	1.9188	50.800	0	35	2.8917
2 1/8	2.1250	2.0844	2.0438	53.975	0	33	3.2807
2 1/4	2.2500	2.2094	2.1688	57.150	0	31	3.6943
2 3/8	2.3750	2.3344	2.2938	60.325	0	29	4.1324
2 1/2	2.5000	2.4594	2.4188	63.500	0	28	4.5950
2 3/4	2.7500	2.7094	2.6688	69.850	0	25	5.5940
3	3.0000	2.9594	2.9188	76.200	0	23	6.6911
3 1/4	3.2500	3.2094	3.1688	82.550	0	21	7.8864
3 1/2	3.5000	3.4594	3.4188	88.900	0	20	9.1799
3 3/4	3.7500	3.7094	3.6688	95.250	0	18	10.5715
4	4.0000	3.9594	3.9188	101.600	0	17	12.0614

[1] Standard size of the American National fine-thread series.

TABLE 10.—LIMITING DIMENSIONS AND TOLERANCES, CLASSES 2 AND 3 FITS, AMERICAN NATIONAL 8-PITCH THREAD SERIES

Dimensions and Tolerances,[1] in Inches		Size, in Inches												
		1[2]	1⅛	1¼	1⅜	1½	1⅝	1¾	1⅞	2	2⅛	2¼	2½	2¾
BOLTS AND SCREWS														
Classes 2 and 3, major diameter	Max.	1.0000	1.1250	1.2500	1.3750	1.5000	1.6250	1.7500	1.8750	2.0000	2.1250	2.2500	2.5000	2.7500
	Min.	0.9848	1.1098	1.2348	1.3598	1.4848	1.6098	1.7348	1.8598	1.9848	2.1098	2.2348	2.4848	2.7348
	Tol.	0.0152	0.0152	0.0152	0.0152	0.0152	0.0152	0.0152	0.0152	0.0152	0.0152	0.0152	0.0152	0.0152
Classes 2 and 3, minor diameter	Max.[3]	0.8466	0.9716	1.0966	1.2216	1.3466	1.4716	1.5966	1.7216	1.8466	1.9716	2.0966	2.3466	2.5966
Class 2, pitch diameter (for general use)	Max.	0.9188	1.0438	1.1688	1.2938	1.4188	1.5438	1.6688	1.7938	1.9188	2.0438	2.1688	2.4188	2.6688
	Min.	0.9112	1.0359	1.1605	1.2852	1.4098	1.5345	1.6591	1.7838	1.9084	2.0331	2.1578	2.4071	2.6564
	Tol.	0.0076	0.0079	0.0083	0.0086	0.0090	0.0093	0.0097	0.0100	0.0104	0.0107	0.0110	0.0117	0.0124
Class 3, pitch diameter	Max.	0.9188	1.0438	1.1688	1.9238	1.4188	1.5438	1.6688	1.7938	1.9188	2.0438	2.1688	2.4188	2.6688
	Min.	0.9134	1.0383	1.1630	1.2877	1.4125	1.5373	1.6620	1.7868	1.9115	2.0363	2.1611	2.4106	2.6601
	Tol.	0.0054	0.0055	0.0058	0.0061	0.0063	0.0065	0.0068	0.0070	0.0073	0.0075	0.0077	0.0082	0.0087
NUTS AND TAPPED HOLES														
Classes 2 and 3, major diameter	Min.[4]	1.0000	1.1250	1.2500	1.3750	1.5000	1.6250	1.7500	1.8750	2.0000	2.1250	2.2500	2.5000	2.7500
Classes 2 and 3, minor diameter	Min.	0.8647	0.9897	1.1147	1.2397	1.3647	1.4897	1.6147	1.7397	1.8647	1.9897	2.1147	2.3647	2.6147
	Max.[5]	0.8795	1.0045	1.1295	1.2545	1.3795	1.5045	1.6295	0.7545	1.8795	2.0045	2.1295	2.3795	2.6295
	Tol.	0.0148	0.0148	0.0148	0.0148	0.0148	0.0148	0.0148	0.0148	0.0148	0.0148	0.0148	0.0148	0.0148
Classes 2 and 3, pitch diameter	Min.	0.9188	1.0438	1.1688	1.2938	1.4188	1.5438	1.6688	1.7938	1.9188	2.0438	2.1688	2.4188	2.6688
Class 2, pitch diameter (for general use)	Max.[6]	0.9264	1.0517	1.1771	1.3024	1.4278	1.5531	1.6785	1.8038	1.9292	2.0545	2.1798	2.4305	2.6812
	Tol.	0.0076	0.0079	0.0083	0.0086	0.0090	0.0093	0.0097	0.0100	0.0104	0.0107	0.0110	0.0117	0.0124
Class 3, pitch diameter	Max.[6]	0.9242	1.0493	1.1746	1.2999	1.4251	1.5503	1.6756	1.8008	1.9261	2.0513	2.1765	2.4270	2.6775
	Tol.	0.0054	0.0055	0.0058	0.0061	0.0063	0.0065	0.0068	0.0070	0.0073	0.0075	0.0077	0.0082	0.0087
		3	3¼	3½	3¾	4	4¼	4½	4¾	5	5¼	5½	5¾	6
Classes 2 and 3, major diameter	Max.	3.0000	3.2500	3.5000	3.7500	4.0000	4.2500	4.5000	4.7500	5.0000	5.2500	5.5000	5.7500	6.0000
	Min.	2.9848	3.2348	3.4848	3.7348	3.9848	4.2348	4.4848	4.7348	4.9848	5.2348	5.4848	5.7348	5.9848
	Tol.	0.0152	0.0152	0.0152	0.0152	0.0152	0.0152	0.0152	0.0152	0.0152	0.0152	0.0152	0.0152	0.0152
Classes 2 and 3, minor diameter	Max.[3]	2.8466	3.0966	3.3466	3.5966	3.8466	4.0966	4.3466	4.5966	4.8466	5.0966	5.3466	5.5966	5.8466
Class 2, pitch diameter for general use)	Max.	2.9188	3.1688	3.4188	3.6688	3.9188	4.1688	4.4188	4.6688	4.9188	5.1688	5.4188	5.6688	5.9188
	Min.	2.9058	3.1556	3.4055	3.6554	3.9053	4.1551	4.4050	4.6549	4.9048	5.1547	5.4046	5.6545	5.9044
	Tol.	0.0130	0.0132	0.0133	0.0134	0.0135	0.0137	0.0138	0.0139	0.0140	0.0141	0.0142	0.0143	0.0144

TABLE 10.—LIMITING DIMENSIONS AND TOLERANCES, CLASSES 2 AND 3 FITS, AMERICAN NATIONAL 8-PITCH THREAD SERIES.—*Continued*

Dimensions and Tolerances[1] in Inches		Size, in Inches												
		3	3¼	3½	3¾	4	4¼	4½	4¾	5	5¼	5½	5¾	6
BOLTS AND SCREWS														
Class 3, pitch diameter	Max.	2.9188	3.1688	3.4188	3.6688	3.9188	4.1688	4.4188	4.6688	4.9188	5.1688	5.4188	5.6688	5.9188
	Min.	2.9096	3.1595	3.4095	3.6594	3.9093	4.1592	4.4091	4.6590	4.9089	5.1589	5.4088	5.6587	5.9086
	Tol.	0.0092	0.0093	0.0093	0.0094	0.0095	0.0096	0.0097	0.0098	0.0099	0.0099	0.0100	0.0101	0.0102
NUTS AND TAPPED HOLES														
Classes 2 and 3, major diameter.............	Min.[4]	3.0000	3.2500	3.5000	3.7500	4.0000	4.2500	4.5000	4.7500	5.0000	5.2500	5.5000	5.7500	6.0000
Classes 2 and 3, minor diameter...........	Min.	2.8647	3.1147	3.3647	3.6147	3.8647	4.1147	4.3647	4.6147	4.8647	5.1147	5.3647	5.6147	5.8647
	Max.	2.8795	3.1295	3.3795	3.6295	3.8795	4.1295	4.3795	4.6295	4.8795	5.1295	5.3795	5.6295	5.8795
	Tol.	0.0148	0.0148	0.0148	0.0148	0.0148	0.0148	0.0148	0.0148	0.0148	0.0148	0.0148	0.0148	0.0148
Classes 2 and 3, pitch diameter..............	Min.	2.9188	3.1688	3.4188	3.6688	3.9188	4.1688	4.4188	4.6688	4.9188	5.1688	5.4188	5.6688	5.9188
Class 2, pitch diameter (fore general use)...	Max.[5]	2.9318	3.1820	3.4321	3.6822	3.9323	4.1825	4.4326	4.6827	4.9328	5.1829	5.4330	5.6831	5.9332
	Tol.	0.0130	0.0132	0.0133	0.0134	0.0135	0.0137	0.0138	0.0139	0.0140	0.0141	0.0142	0.0143	0.0144
Class 3, pitch diameter	Max.[5]	2.9280	3.1781	3.4281	3.6782	3.9283	4.1784	4.4285	4.6786	4.9287	5.1787	5.4288	5.6789	5.9290
	Tol.	0.0092	0.0093	0.0093	0.0094	0.0095	0.0096	0.0097	0.0098	0.0099	0.0099	0.0100	0.0101	0.0102

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[1] Pitch diameter tolerances include errors of lead and angle. The class 2 tolerances are based on the formulas on page 22 and a length of engagement equal to the basic major diameter for sizes from 1⅛ to 3 inches, inclusive, and a length of engagement of 3 inches for sizes over the 3-inch. The class 3 tolerances are 70 per cent of the class 2 tolerances. The 1-inch size being in the American National coarse-thread series, the tolerances for this size correspond to that series.

[2] Standard size screw and nut of the American National coarse-thread series.

[3] Dimensions given for the maximum minor diameter of the screw are figured to the intersection of the worn tool arc with a center line through crest and root. The minimum minor diameter of the screw shall be that corresponding to a flat at the minor diameter of the minimum screw equal to $\frac{1}{8} \times p$, and may be determined by subtracting 0.0812 inch from the minimum pitch diameter of the screw.

[4] Dimensions for the minimum major diameter of the nut correspond to the basic flat ($\frac{1}{8} \times p$), and the profile at the major diameter produced by a worn tool must not fall below the basic outline. The maximum major diameter of the nut shall be that corresponding to a flat at the major diameter of the maximum nut equal to $\frac{1}{24} \times p$, and may be determined by adding 0.0992 inch to the maximum pitch diameter of the nut.

[5] These dimensions are the minimum metal or "not go" size. The "go" or basic size is the one that should be placed on the component drawing with the tolerance.

TABLE 11.—LIMITING DIMENSIONS AND TOLERANCES, CLASSES 2 AND 3 FITS, AMERICAN NATIONAL 12-PITCH THREAD SERIES

Dimensions and Tolerances[1]		Size, in Inches														
		1/2	9/16[2]	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/16	1 1/8[3]	1 3/16	1 1/4[3]	1 5/16	1 3/8[3]
BOLTS AND SCREWS																
Classes and 3, major diam.	Max.	0.5000	0.5625	0.6250	0.6875	0.7500	0.8125	0.8750	0.9375	1.0000	1.0625	1.1250	1.1875	1.2500	1.3125	1.3750
	Min.	0.4888	0.5513	0.6138	0.6763	0.7388	0.8013	0.8638	0.9263	0.9888	1.0513	1.1138	1.1763	1.2388	1.3013	1.3638
	Tol.	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112
Classes 2 and 3, minor diam.	Max.[4]	0.3978	0.4603	0.5228	0.5853	0.6478	0.7103	0.7728	0.8353	0.8978	0.9603	1.0228	1.0853	1.1478	1.2103	1.2728
Class 2, pitch diam. (for general use)	Max.	0.4459	0.5084	0.5709	0.6334	0.6959	0.7584	0.8209	0.8834	0.9459	1.0084	1.0709	1.1334	1.1959	1.2584	1.3209
	Min.	0.4403	0.5028	0.5653	0.6278	0.6903	0.7528	0.8153	0.8778	0.9403	1.0028	1.0653	1.1278	1.1903	1.2528	1.3153
	Tol.	0.0056	0.0056	0.0056	0.0056	0.0056	0.0056	0.0056	0.0056	0.0056	0.0056	0.0056	0.0056	0.0056	0.0056	0.0056
Class 3, pitch diam.	Max.	0.4459	.05084	0.5709	0.6334	0.6959	0.7584	0.8209	0.8834	0.9459	1.0084	1.0709	1.1334	1.1959	1.2584	1.3209
	Min.	0.4419	0.5044	0.5669	0.6294	0.6919	0.7544	0.8169	0.8794	0.9419	1.0044	1.0669	1.1294	1.1919	1.2544	1.3169
	Tol.	0.0040	.00040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	.00040	0.0040
NUTS AND TAPPED HOLES																
Classes 2 and 3, major diam.	Min.[5]	0.5000	0.5625	0.6250	0.6875	0.7500	0.8125	0.8750	0.9375	1.0000	1.0625	1.1250	1.1875	1.2500	1.3125	1.3750
Classes 2 and 3, minor diam.	Min.	0.4098	0.4723	0.5348	0.5973	0.6598	0.7223	0.7848	0.8473	0.9098	0.9723	1.0348	1.0973	1.1598	1.2223	1.2848
	Max.	0.4225	0.4850	0.5438	0.6063	0.6688	0.7313	0.7938	0.8563	0.9188	0.9813	1.0438	1.1063	1.1688	1.2313	1.2938
	Tol.	0.0127	0.0127	0.0090	.00090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090
Classes 2 and 3, pitch diam.	Min.	0.4459	0.5084	0.5709	0.6334	0.6959	0.7584	0.8209	0.8834	0.9459	1.0084	1.0709	1.1334	1.1959	1.2584	1.3209
Class 2, pitch diam (for general use)	Max.[6]	0.4515	0.5140	0.5765	0.6390	0.7015	0.7640	0.8265	0.8890	0.9515	1.0140	1.0765	1.1390	1.2015	1.2640	1.3265
	Tol.	0.0056	0.0056	0.0056	0.0056	0.0056	0.0056	0.0056	0.0056	0.0056	0.0056	0.0056	0.0056	0.0056	0.0056	0.0056
Class 3, pitch diam.	Max.[6]	0.4499	0.5124	0.5749	0.6374	0.6999	0.7624	0.8249	0.8874	0.9499	1.0124	1.0749	1.1374	1.1999	1.2624	1.3249
	Tol.	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040

TABLE 11.—LIMITING DIMENSIONS AND TOLERANCES, CLASSES 2 AND 3 FITS, AMERICAN NATIONAL 12-PITCH THREAD SERIES.—*Continued*

Dimensions and Tolerances[1]		Size, in Inches														
		1 7/16	1½[3]	1⅝	1¾	1⅞	2	2⅛	2¼	2⅜	2½	2⅝	2¾	2⅞	3	3⅛
BOLTS AND SCREWS																
Classes 2 and 3, major diam.	Max.	1.4375	1.5000	1.6250	1.7500	1.8750	2.0000	2.1250	2.2500	2.3750	2.5000	2.6250	2.7500	2.8750	3.0000	3.1250
	Min.	1.4263	1.4888	1.6138	1.7388	1.8638	1.9888	2.1138	2.2388	2.3638	2.4888	2.6138	2.7388	2.8638	2.9888	3.1138
	Tol.	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112
Classes 2 and 3, minor diam.	Max.[4]	1.3353	1.3978	1.5228	1.6478	1.7728	1.8978	2.0228	2.1478	2.2728	2.3978	2.5228	2.6478	2.7728	2.8978	3.0228
Class 2, pitch diam. (for general use)	Max.	1.3834	1.4459	1.5709	1.6959	1.8209	1.9459	2.0709	2.1959	2.3209	2.4459	2.5709	2.6959	2.8209	2.9459	3.0709
	Min.	1.3778	1.4403	1.5645	1.6894	1.8143	1.9392	2.0641	2.1890	2.3139	2.4388	2.5638	2.6887	2.8136	2.9385	3.0635
	Tol.	0.0056	0.0056	0.0064	0.0065	0.0066	0.0067	0.0068	0.0069	0.0070	0.0071	0.0071	0.0072	0.0073	0.0074	0.0074
Class 3, pitch diam.	Max.	1.3834	1.4459	1.5709	1.6959	1.8209	1.9459	2.0709	2.1959	2.3209	2.4459	2.5709	2.6959	2.8209	2.9459	3.0709
	Min.	1.3794	1.4419	1.5664	1.6913	1.8163	1.9412	2.0661	2.1911	2.3160	2.4410	2.5659	2.6909	2.8158	2.9408	3.0657
	Tol.	0.0040	0.0040	0.0045	0.0046	0.0046	0.0047	0.0048	0.0048	0.0049	0.0049	0.0050	0.0050	0.0051	0.0051	0.0052
NUTS AND TAPPED HOLES																
Classes 2 and 3, major diam.	Min.[5]	1.4375	1.5000	1.6250	1.7500	1.8750	2.0000	2.1250	2.2500	2.3750	2.5000	2.6250	2.7500	2.8750	3.0000	3.1250
Classes 2 and 3, minor diam.	Min.	1.3473	1.4098	1.5348	1.6598	1.7848	1.9098	2.0348	2.1598	2.2848	2.4098	2.5348	2.6598	2.7848	2.9098	3.0348
	Max.	1.3563	1.4188	1.5438	1.6688	1.7938	1.9188	2.0438	2.1688	2.2938	2.4188	2.5438	2.6688	2.7938	2.9188	3.0438
	Tol.	0.0090	0.0090	0.0090	0.0090	0.0090	0 0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090
Classes 2 and 3, pitch diam.	Min.	1.3834	1.4459	1.5709	1.6959	1.8209	1.9459	2.0709	2.1959	2.3209	2.4459	2.5709	2.6959	2.8209	2.9459	3.0709
Class 2, pitch diam. (for general use)	Max.[6]	1.3890	1.4515	1.5773	1.7024	1.8275	1.9526	2.0777	2.2028	2.3279	2.4530	2.5780	2.7031	2.8282	2.9533	3.0783
	Tol.	0.0056	0.0056	0.0064	0.0065	0.0066	0.0067	0.0068	0.0069	0.0070	0.0071	0.0071	0.0072	0.0073	0.0074	0.0074
Class 3, pitch diam.	Max.[6]	1.3874	1.4499	1.5754	1.7005	1.8255	1.9506	2.0757	2.2007	2.3258	2.4508	2.5759	2.7009	2.8260	2.9510	3.0761
	Tol.	0.0040	0.0040	0.0045	0.0046	0.0046	0.0047	0.0048	0.0048	0.0049	0.0049	0.0050	0.0050	0.0051	0.0051	0.0052

See footnotes at end of table.

TABLE 11.—LIMITING DIMENSIONS AND TOLERANCES, CLASSES 2 AND 3 FITS, AMERICAN NATIONAL 12-PITCH THREAD SERIES.—*Continued*

Dimensions and Tolerances[1]		Size, in Inches														
		3¼	3⅜	3½	3⅝	3¾	3⅞	4	4¼	4½	4¾	5	5¼	5½	5¾	6
BOLTS AND SCREWS																
Classes 2 and 3, major diam	Max.	3.2500	3.3750	3.5000	3.6250	3.7500	3.8750	4.0000	4.2500	4.5000	4.7500	5.0000	5.2500	5.5000	5.7500	6.0000
	Min.	2.2388	3.3638	3.4888	3.6138	3.7388	3.8638	3.9888	4.2388	4.4888	4.7388	4.9888	5.2388	5.4888	5.7388	5.9888
	Tol.	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112
Classes 2 and 3, minor diam.	Max.[4]	3.1478	3.2728	3.3978	3.5228	3.6478	3.7728	3.8978	4.1478	4.3978	4.6478	4.8978	5.1478	5.3978	5.6478	5.8978
Class 2 pitch diam (for general use)	Max.	3.1959	3.3209	3.4459	3.5709	3.6959	3.8209	3.9459	4.1959	4.4459	4.6959	4.9459	5.1959	5.4459	5.6959	5.9459
	Min.	3.1884	3.3133	3.4383	3.5632	3.6881	3.8131	3.9380	4.1879	4.4378	4.6876	4.9375	5.1874	5.4373	5.6872	5.9371
	Tol.	0.0075	0.0076	0.0076	0.0077	0.0078	0.0078	0.0079	0.0080	0.0081	0.0083	0.0084	0.0085	0.0086	0.0087	0.0088
Class 3, pitch diam	Max.	3.1959	3.3209	3.4459	3.5709	3.6959	3.8209	3.9459	4.1959	4.4459	4.6959	4.9459	5.1959	5.4459	5.6959	5.9459
	Min.	3.1907	3.3156	3.4406	3.5655	3.6905	3.8154	3.9404	4.1903	4.4402	4.6901	4.9400	5.1900	5.4399	5.6898	5.9397
	Tol.	0.0052	0.0053	0.0053	0.0054	0.0054	0.0055	0.0055	0.0056	0.0057	0.0058	0.0059	0.0059	0.0060	0.0061	0.0062

NUTS AND TAPPED HOLES																
Classes 2 and 3, major diam.	Min.[5]	3.2500	3.3750	3.5000	3.6250	3.7500	3.8750	4.0000	4.2500	4.5000	4.7500	5.0000	5.2500	5.5000	5.7500	6.0000
Class 2 and 3, minor diam.	Min.	3.1598	3.2848	3.4098	3.5348	3.6598	3.7848	3.9098	4.1598	4.4098	4.6598	4.9098	5.1598	5.4098	5.6598	5.9098
	Max.	3.1688	3.2938	3.4188	3.5438	3.6688	3.7938	3.9188	4.1688	4.4188	4.6688	4.9188	5.1688	5.4188	5.6688	5.9188
	Tol.	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090
Classes 2 and 3, pitch diam.	Min.	3.1959	3.3209	3.4459	3.5709	3.6959	3.8209	3.9459	4.1959	4.4459	4.6959	4.9459	5.1959	5.4459	5.6959	5.9459
Class 2 pitch diam (for general use)	Max.[6]	3.2034	3.3285	3.4535	3.5786	3.7037	3.8287	3.9538	4.2039	4.4540	4.7042	4.9543	5.2044	5.4545	5.7046	5.9547
	Tol.	0.0075	0.0076	0.0076	0.0077	0.0078	0.0078	0.0079	0.0080	0.0081	0.0083	0.0084	0.0085	0.0086	0.0087	0.0088
Class 3, pitch diam	Max.[6]	3.2011	2.3262	3.4512	3.5763	3.7013	3.8264	3.9514	4.2015	4.4516	4.7017	4.9518	5.2018	5.4519	5.7020	5.9521
	Tol.	0.0052	0.0053	0.0053	0.0054	0.0054	0.0055	0.0055	0.0056	0.0057	0.0058	0.0059	0.0059	0.0060	0.0061	0.0062

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[1] Pitch-diameter tolerances include errors of lead and angle. The class 2 tolerances for sizes above 1½ inches are based on the formulas in Table 9*a* and a length of engagement of 6 threads or ½ inch. The class 3 tolerances are 70 per cent of the class 2 tolerances. For lengths of engagement of 1 inch, 0.0010 inch may be added to these tolerances. As certain sizes up to 1½ inches are included in the American National coarse- or fine-thread series, the tolerances to and including 1½ inches correspond to those series.

[2] Standard-size screw and nut of the American National coarse-thread series.

[3] Standard-size screw and nut of the American National fine-thread series.

[4] Dimensions given for the maximum minor diameter of the screw are figured to the intersection of the worn tool arc with a center line through crest and root. The minimum minor diameter of the screw shall be that corresponding to a flat at the minor diameter of the minimum screw equal to $\frac{1}{8} \times p$, and may be determined by subtracting 0.0541 inch from the minimum pitch diameter of the screw.

[5] Dimensions for the minimum major diameter of the nut correspond to the basic flat ($\frac{1}{8} \times p$) and the profile at the major diameter produced by a worn tool must not fall below the basic outline. The maximum major diameter of the nut shall be that corresponding to a flat at the major diameter of the maximum nut equal to $\frac{1}{24} \times p$, and may be determined by adding 0.0662 inch to the maximum pitch diameter of the nut.

[6] These dimensions are the minimum metal or "not go" size. The "go" or basic size is the one that should be placed on the component drawing with the tolerance.

TABLE 12.—LIMITING DIMENSIONS AND TOLERANCES, CLASSES 2 AND 3 FIT, AMERICAN NATIONAL 16-PITCH-THREAD SERIES

Dimensions and Tolerances[1]		Size, in Inches									
		3/4	13/16	7/8	15/16	1	1 1/16	1 1/8	1 3/16	1 1/4	1 5/16
BOLTS AND SCREWS											
Major diameter	Max.	0.7500	0.8125	0.8750	0.9375	1.0000	1.0625	1.1250	1.1875	1.2500	1.3125
	Min.	0.7410	0.8035	0.8660	0.9285	0.9910	1.0535	1.1160	1.1785	1.2410	1.3035
	Tol.	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090
Minor diameter	Max.[3]	0.6733	0.7358	0.7983	0.8608	0.9233	0.9858	1.0483	1.1108	1.1733	1.2358
Class 2, pitch diameter for (general use)	Max.	0.7094	0.7719	0.8344	0.8969	0.9594	1.0219	1.0844	1.1469	1.2094	1.2719
	Min.	0.7049	0.7668	0.8293	0.8917	0.9542	1.0166	1.0790	1.1415	1.2039	1.2664
	Tol.	0.0045	0.0051	0.0051	0.0052	0.0052	0.0053	0.0054	0.0054	0.0055	0.0055
Class 3, pitch diameter	Max.	0.7094	0.7719	0.8344	0.8969	0.9594	1.0219	1.0844	1.1469	1.2094	1.2719
	Min.	0.7062	0.7684	0.8308	0.8933	0.9557	1.0182	1.0806	1.1431	1.2056	1.2680
	Tol.	0.0032	0.0035	0.0036	0.0036	0.0037	0.0037	0.0038	0.0038	0.0038	0.0039
NUTS AND TAPPED HOLES											
Major diameter	Min.[4]	0.7500	0.8125	0.8750	0.9375	1.0000	1.0625	1.1250	1.1875	1.2500	1.3125
Minor diameter	Min.	0.6823	0.7448	0.8073	0.8698	0.9323	0.9948	1.0573	1.1198	1.1823	1.2448
	Max.[5]	0.6903	0.7528	0.8153	0.8778	0.9403	1.0028	1.0653	1.1278	1.1903	1.2528
	Tol.	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080
Class 2, pitch diameter (for general use)	Min.	0.7094	0.7719	0.8344	0.8969	0.9594	1.0219	1.0844	1.1469	1.2094	1.2719
	Max.	0.7139	0.7770	0.8395	0.9021	0.9646	1.0272	1.0898	1.1523	1.2149	1.2774
	Tol.	0.0045	0.0051	0.0051	0.0052	0.0052	0.0053	0.0054	0.0054	0.0055	0.0055
Class 3, pitch diameter	Min.	0.7094	0.7719	0.8344	0.8969	0.9594	1.0219	1.0844	1.1469	1.2094	1.2719
	Max.	0.7126	0.7754	0.8380	0.9005	0.9631	1.0256	1.0882	1.1507	1.2132	1.2758
	Tol.	0.0032	0.0035	0.0036	0.0036	0.0037	0.0037	0.0038	0.0038	0.0038	0.0039

TABLE 12.—LIMITING DIMENSIONS AND TOLERANCES, CLASSES 2 AND 3 FIT, AMERICAN NATIONAL 16-PITCH-THREAD SERIES.—*Continued*

Dimensions and Tolerances[1]		Size, in Inches									
		1 3/8	1 7/16	1 1/2	1 9/16	1 5/8	1 11/16	1 3/4	1 13/16	1 7/8	1 15/16
BOLTS AND SCREWS											
Major diameter	Max.	1.3750	1.4375	1.5000	1.5625	1.6250	1.6875	1.7500	1.8125	1.8750	1.9375
	Min.	1.3660	1.4285	1.4910	1.5535	1.6160	1.6785	1.7410	1.8035	1.8660	1.9285
	Tol.	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090
Minor diameter	Max.[3]	1.2983	1.3608	1.4233	1.4858	1.5483	1.6108	1.6733	1.7358	1.7983	1.8608
Class 2, pitch diameter (for general use)	Max.	1.3344	1.3969	1.4594	1.5219	1.5844	1.6469	1.7094	1.7719	1.8344	1.8969
	Min.	1.3288	1.3913	1.4537	1.5161	1.5786	1.6411	1.7035	1.7660	1.8284	1.8909
	Tol.	0.0056	0.0056	0.0057	0.0058	0.0058	0.0058	0.0059	0.0059	0.0060	0.0060
Class 3, pitch diameter	Max.	1.3344	1.3969	1.4594	1.5219	1.5844	1.6469	1.7094	1.7719	1.8344	1.8969
	Min.	1.3305	1.3929	1.4554	1.5179	1.5803	1.6428	1.7053	1.7677	1.8302	1.8927
	Tol.	0.0039	0.0040	0.0040	0.0040	0.0041	0.0041	0.0041	0.0042	0.0042	0.0042
NUTS AND TAPPED HOLES											
Major diameter	Min.[4]	1.3750	1.4375	1.5000	1.5625	1.6250	1.6875	1.7500	1.8125	1.8750	1.9375
Minor diameter	Min.	1.3073	1.3698	1.4323	1.4948	1.5573	1.6198	1.6823	1.7448	1.8073	1.8698
	Max.[5]	1.3153	1.3778	1.4403	1.5028	1.5653	1.6278	1.6903	1.7528	1.8156	1.8778
	Tol.	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080
Class 2, pitch diameter (for general use)	Min.	1.3344	1.3969	1.4594	1.5219	1.5844	1.6469	1.7094	1.7719	1.8344	1.8969
	Max.	1.3400	1.4025	1.4561	1.5277	1.5902	1.6527	1.7153	1.7778	1.8404	1.9029
	Tol.	0.0056	0.0056	0.0057	0.0058	0.0058	0.0058	0.0059	0.0059	0.0060	0.0060
Class 3, pitch diameter	Min.	1.3344	1.3969	1.4594	1.5219	1.5844	1.6469	1.7094	1.7719	1.8344	1.8969
	Max.	1.3383	1.4009	1.4634	1.5259	1.5885	1.6510	1.7135	1.7761	1.8386	1.9011
	Tol.	0.0039	0.0040	0.0040	0.0040	0.0041	0.0041	0.0041	0.0042	0.0042	0.0042

See footnotes at end of table.

TABLE 12.—LIMITING DIMENSIONS AND TOLERANCES, CLASSES 2 AND 3 FIT, AMERICAN NATIONAL 16-PITCH-THREAD SERIES.—*Continued*

Dimensions and Tolerances[1]		Size, in Inches									
		2	2 1/16	2 1/8	2 3/16	2 1/4	2 5/16	2 3/8	2 7/16	2 1/2	2 5/8
BOLTS AND SCREWS											
Major diameter	Max.	2.0000	2.0625	2.1250	2.1875	2.2500	2.3125	2.3750	2.4375	2.5000	2.6250
	Min.	1.9910	2.0535	2.1160	2.1785	2.2410	2.3035	2.3660	2.4285	2.4910	2.6160
	Tol.	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090
Minor diameter	Max.[3]	1.9233	1.9858	2.0483	2.1108	2.1733	2.2358	2.2983	2.3608	2.4233	2.5483
Class 2, pitch diameter (for general use)	Max.	1.9594	2.0219	2.0844	2.1469	2.2094	2.2719	2.3344	2.3969	2.4594	2.5844
	Min.	1.9533	2.0158	2.0782	2.1407	2.2032	2.2656	2.3281	2.3905	2.4530	2.5779
	Tol.	0.0061	0.0061	0.0062	0.0062	0.0062	0.0063	0.0063	0.0064	0.0064	0.0065
Class 3, pitch diameter	Max.	1.9594	2.0219	2.0844	2.1469	2.2094	2.2719	2.3344	2.3969	2.4594	2.5844
	Min.	1.9551	2.0176	2.0801	2.1426	2.2050	2.2675	2.3300	2.3924	2.4549	2.5799
	Tol.	0.0043	0.0043	0.0043	0.0043	0.0044	0.0044	0.0044	0.0045	0.0045	0.0045
NUTS AND TAPPED HOLES											
Major diameter	Min.[4]	2.0000	2.0625	2.1250	2.1875	2.2500	2.3125	2.3750	2.4375	2.5000	2.6250
Minor diameter	Min.	1.9323	1.9948	2.0573	2.1198	2.1823	2.2448	2.3073	2.3698	2.4323	2.5573
	Max.[5]	1.9403	2.0028	2.0653	2.1278	2.1903	2.2528	2.3153	2.3778	2.4403	2.5653
	Tol.	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080
Class 2, pitch diameter (for general use	Min.	1.9594	2.0219	2.0844	2.1469	2.2094	2.2719	2.3344	2.3969	2.4594	2.5844
	Max.	1.9655	2.0280	2.0906	2.1531	2.2156	2.2782	2.3407	2.4033	2.4658	2.5909
	Tol.	0.0061	0.0061	0.0062	0.0062	0.0062	0.0063	0.0063	0.0064	0.0064	0.0065
Class 3, pitch diameter	Min.	1.9594	2.0219	2.0844	2.1469	2.2094	2.2719	2.3344	2.3969	2.4594	2.5844
	Max.	1.9637	2.0262	2.0887	2.1512	2.2138	2.2763	2.3388	2.4014	2.4639	2.5889
	Tol.	0.0043	0.0043	0.0043	0.0043	0.0044	0.0044	0.0044	0.0045	0.0045	0.0045

Dimensions and Tolerances[1]		Size, in Inches										
		2¾	2⅞	3	3⅛	3¼	3⅜	3½	3⅝	3¾	3⅞	4
BOLTS AND SCREWS												
Major diameter	Max.	2.7500	2.8750	3.0000	3.1250	3.2500	3.3750	3.5000	3.6250	3.7500	3.8750	4.0000
	Min.	2.7410	2.8660	2.9910	3.1160	3.2410	3.3660	3.4910	3.6160	3.7410	3.8660	3.9910
	Tol.	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090
Minor diameter	Max.[3]	2.6733	2.7983	2.9233	3.0483	3.1733	3.2983	3.4233	3.5483	3.6733	3.7983	3.9233
Class 2, pitch diameter (for general use)	Max.	2.7094	2.8344	2.9594	3.0844	3.2094	3.3344	3.4594	3.5844	3.7094	3.8344	3.9594
	Min.	2.7028	2.8278	2.9527	3.0776	3.2025	3.3275	3.4524	3.5773	3.7023	3.8272	3.9522
	Tol.	0.0066	0.0066	0.0067	0.0068	0.0069	0.0069	0.0070	0.0071	0.0071	0.0072	0.0072
Class 3, pitch diameter	Max.	2.7094	2.8344	2.9594	3.0844	3.2094	3.3344	3.4594	3.5844	3.7094	3.8344	3.9594
	Min.	2.7048	2.8298	2.9547	3.0797	3.2046	3.3296	3.4545	3.5795	3.7044	3.8294	3.9543
	Tol.	0.0046	0.0046	0.0047	0.0047	0.0048	0.0048	0.0049	0.0049	0.0050	0.0050	0.0051
NUTS AND TAPPED HOLES												
Major diameter	Min.[4]	2.7500	2.8750	3.0000	3.1250	3.2500	3.3750	3.5000	3.6250	3.7500	3.8750	4.0000
Minor diameter	Min.	2.6823	2.8073	2.9323	3.0573	3.1823	3.3073	3.4323	3.5573	3.6823	3.8073	3.9323
	Max.	2.6903	2.8153	2.9403	3.0653	3.1903	3.3153	3.4403	3.5653	3.6903	3.8153	3.9403
	Tol.	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080
Class 2, pitch diameter (for general use)	Min.	2.7094	2.8344	2.9594	3.0844	3.2094	3.3344	3.4594	3.5844	3.7094	3.8344	3.9594
	Max.	2.7160	2.8410	2.9661	3.0912	3.2163	3.3413	3.4664	3.5915	3.7165	3.8416	3.9666
	Tol	0.0066	0.0066	0.0067	0.0068	0.0069	0.0069	0.0070	0.0071	0.0071	0.0072	0.0072
lass 3, pitch diameter	Min.	2.7094	2.8344	2.9594	3.0844	3.2094	3.3344	3.4594	3.5844	3.7094	3.8344	3.9594
	Max.	2.7140	2.8390	2.9641	3.0891	3.2142	3.3392	3.4643	3.5893	3.7144	3.8394	3.9645
	Tol.	0.0046	0.0046	0.0047	0.0047	0.0048	0.0047	0.0049	0.0049	0.0050	0.0050	0.0051

---

[1] Pitch diameter tolerances include errors of lead and angle. The class 2 tolerances are based on formulas in Table 9*a* and a length of engagement of 6 threads or ⅜ inch. The class 3 tolerances are 70 per cent of the class 2 tolerances. The ¾-inch size being in the American National fine-thread series, the tolerance for this size corresponds to that series.

[2] Standard-size screw and nut of the American National fine-thread series.

[3] Dimensions given for the maximum minor diameter of the screw are figured to the intersection of the worn-tool arc with a center line through crest and root. The minimum minor diameter of the screw shall be that corresponding to a flat at the minor diameter of the minimum screw equal to $\frac{1}{8} \times p$, and may be determined by subtracting 0.0406 inch from the minimum pitch diameter of the screw.

[4] Dimensions for the minimum major diameter of the nut correspond to the basic flat ($\frac{1}{8} \times p$) and the profile at the major diameter produced by a worn tool must not fall below the basic outline. The maximum major diameter of the nut shall be that corresponding to a flat at the major diameter of the maximum nut equal to $\frac{1}{24} \times p$, and may be determined by adding 0.0496 inch to the maximum pitch diameter of the nut.

Data Referring to Figs. 2*a* to 2*d*

SYMBOLS AND VALUES

D = major diameter, nominal and basic

D_n = major diameter of nut = D

D_s = major diameter of screw = $D - V$

E = pitch (effective) diameter, basic = $D - h$

E_n = pitch (effective) diameter of nut = $D - h$

[1]E_s = pitch (effective) diameter of screw classes 1½, 2, and 3 = $D - h$

F_c = crest width, minimum = $0.243624p$

F_r = root width, maximum = $0.166667p$

F_s = minimum width of flat, new chaser = $\frac{p}{12}$

F_t = minimum width of flat, new tap = $\frac{p}{20}$

H = height of basic triangle = $0.960491p$

h = depth of basic thread = $0.640327p$

J = allowance at pitch (effective) diameter = $0.05q = 002832p$

K = minor diameter, basic = $D - 2h$

K_n = minor diameter of nut = $D - 2q$

[2]K_s = minor diameter of screw = $D - 2h$

n = number of threads per inch

p = pitch = $\frac{1}{n}$

q = height of truncated thread = $0.566410p$

r = radius of British Standard Whitworth thread = $0.137329p$

V = double the height of segment of British Standard Whitworth crest = $0.147835p$

SCREW

Major diameter, maximum = $D - 0.147835p$

Pitch (effective) diameter, maximum = $D - 0.640327p$

Minor diameter, maximum = $D - 1.280655p$

NUT

Major diameter, minimum = D

Pitch (effective) diameter, minimum = $D - 0.640327p$

Minor diameter, minimum = $D - 1.132820p$

[1] E_s for Class 1 is less than E_s for other classes by value J.

[2] Dimensions computed by use of this formula may vary by 0.0001 inch from dimensions shown in Tables 21, 22, and 23, as these dimensions have been made to agree with BS84-1940.

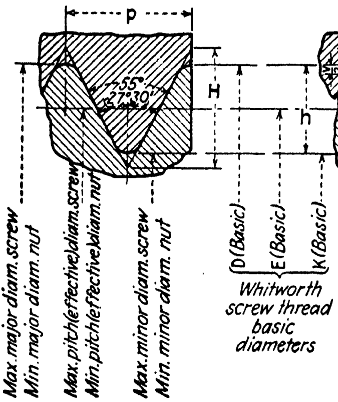

FIG. 2*a*.

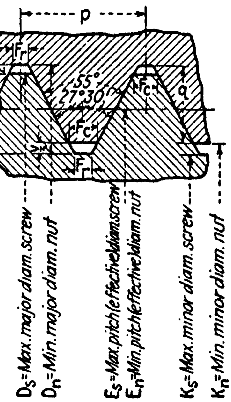

FIG. 2*b*.

FIG. 2*a*.—British Standard Screw Threads of Whitworth Form.
FIG. 2*b*.—Screw Threads of Truncated Whitworth Form.

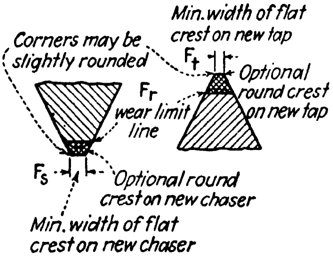
Min. width of flat crest on new tap
Corners may be slightly rounded
Ft
Optional round crest on new tap
Fr
wear limit line
Fs
Optional round crest on new chaser
Min. width of flat crest on new chaser

FIG. 2*c*.

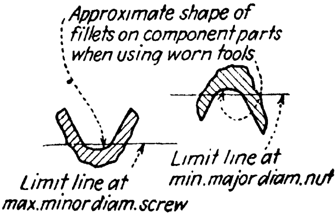
Approximate shape of fillets on component parts when using worn tools
Limit line at max.minor diam.screw
Limit line at min.major diam.nut

FIG. 2*d*.

FIG. 2*c*.—New Chaser (*Left*) and Tap (*Right*).
FIG. 2*d*.—Screw (*Left*) and Nut (*Right*).

BRITISH STANDARD WHITWORTH THREADS

The new standards for threads used in Great Britain are sponsored by the British Standards Institution which has succeeded the British Engineering Standards Association. The terms used are now the same as in the American standard as to major and minor diameters, but they still use "effective diameter" where we use "pitch diameter."

These standards now include a five-thread series and a parallel pipe thread, as will be seen in the tables that follow. They are designated as B. S. Whit, B. S. Five, and B. S. Pipe (Parallel).

These standards do not include the British Association thread of 47½ deg. which is given on page 41. These are dated May, 1940.

TABLE 13.—RADIUS OF WHITWORTH THREADS

Threads per Inch	Radius in Inches	Threads per Inch	Radius in Inches
40	0.0034	9	0.0153
24	0.0057	8	0.0172
20	0.0069	7	0.0196
19	0.0072	6	0.0229
18	0.0076	5	0.0275
16	0.0086	4½	0.0305
14	0.0098	4	0.0343
12	0.0114	3½	0.0392
11	0.0125	3¼	0.0422
10	0.0137	3	0.0458

AMERICAN TRUNCATED WHITWORTH THREADS

American War Standard Screw Threads of Truncated Whitworth Form,[1] to be known as American Truncated Whitworth Threads, have been adopted to facilitate and reduce the cost of a thread that is interchangeable with Standard Whitworth threads, as shown on the following pages.

The tools that produce these threads and the gages that check them will secure interchangeability with Standard Whitworth threads. They *will not* produce the Standard Whitworth profile nor gage Standard Whitworth threads. Plain gages for major and minor diameters of the two systems *cannot* be used interchangeably, as the diameters differ. But Standard Whitworth "go" ring gages, snap gages, and plug gages will accept Truncated Whitworth threads of proper pitch diameter, lead, and angle, making these gages available for both systems. For checking truncated threads these gages must be supplemented by plain gages for measuring major and minor diameters.

All orders should indicate clearly whether the supplier is to produce American Truncated Whitworth Treads according to this standard, or whether either kind of thread will be accepted.

[1] Approved June 19, 1944.

TABLE 14.—SCREW THREADS OF TRUNCATED WHITWORTH FORM
Symbol Values for Each Pitch
(Dimensions in Inches)

Threads per Inch, n	Pitch, p	Depth of Basic Thread, h	Height of Truncated Thread, q	Min. Crest Width, F_c	Max. Root Width, F_r	Min. Width of Flat, New Chaser, F_s	Min. Width of Flat, New Tap, F_t	Allowance at Pitch Diam. (Effect. Diam.) J	Double Height of Segment B.S.W. Crest, V	Per Cent[1]
40	0.025000	0.016008	0.014160	0.0061	0.0042	0.0021	0.00125	0.0007	0.003696	61.0
36	0.027778	0.017787	0.015734	0.0068	0.0046	0.0023	0.0014	0.0008	0.004107	63.8
32	0.031250	0.020010	0.017700	0.0076	0.0052	0.0026	0.0016	0.0009	0.004620	66.9
28	0.035714	0.022869	0.020229	0.0087	0.0060	0.0030	0.0018	0.0010	0.005280	69.6
26	0.038462	0.024628	0.021785	0.0094	0.0064	0.0032	0.0019	0.0011	0.005686	71.0
24	0.041667	0.026681	0.023601	0.0102	0.0069	0.0035	0.0021	0.0012	0.006160	70.0
22	0.045455	0.029106	0.025746	0.0111	0.0076	0.0038	0.0023	0.0013	0.006720	71.4
20	0.050000	0.032016	0.0283205	0.0122	0.0083	0.0042	0.0025	0.0014	0.007392	69.1
18	0.055556	0.035574	0.031467	0.0135	0.0093	0.0046	0.0028	0.0016	0.008213	71.1
16	0.062500	0.040020	0.035401	0.0152	0.0104	0.0052	0.0031	0.0018	0.009240	73.2
14	0.071429	0.045738	0.040458	0.0174	0.0119	0.0060	0.0036	0.0020	0.010560	75.3
12	0.083333	0.053360	0.047201	0.0203	0.0139	0.0069	0.0042	0.0024	0.012320	77.2
11	0.090909	0.058211	0.051492	0.0221	0.0152	0.0076	0.0045	0.0026	0.013440	78.2
10	0.100000	0.064033	0.056641	0.0244	0.0167	0.0083	0.0050	0.0028	0.014784	79.3
9	0.111111	0.071147	0.062934	0.0271	0.0185	0.0093	0.0056	0.0031	0.016426	80.3
8	0.125000	0.080041	0.070801	0.0305	0.0208	0.0104	0.00625	0.0035	0.018479	81.3
7	0.142857	0.091475	0.080916	0.0348	0.0238	0.0119	0.0071	0.0040	0.021119	82.3
6	0.166667	0.106721	0.094402	0.0406	0.0278	0.0139	0.0083	0.0047	0.024639	83.3
5	0.200000	0.128065	0.113282	0.0487	0.0333	0.0167	0.0100	0.0057	0.029567	84.4
4½	0.222222	0.142295	0.125869	0.0541	0.0370	0.0185	0.0111	0.0063	0.032852	84.9
4	0.250000	0.160082	0.141602	0.0609	0.0417	0.0208	0.0125	0.0071	0.036959	85.4
3½	0.285714	0.182950	0.161831	0.0696	0.0476	0.0238	0.0143	0.0081	0.042239	85.9

[1] Minimum flank contact expressed in percentage of basic flank contact =

$$\frac{2(h - V) - (\text{tol. on } D_s + \text{tol. on } K_n)}{2(h - V)} \times 100$$

TABLE 15.—SCREW THREADS OF TRUNCATED WHITWORTH FORM—COARSE THREAD SERIES
(Dimensions in Inches)

Size	Threads per Inch,	Pitch, $\frac{1}{n}$	Screw								Nut						
			Major Diameter Truncated		Pitch (Effective) Diameter					Minor Diam. Max.	Major Diam. Min.	Pitch (Effective) Diameter				Minor Diameter Truncated	
			Max.	Tolerance (Apply Minus) All Classes	Max.		Tolerance (Apply Minus)					Min.	Tolerance (Apply Plus)			Min.	Tolerance (Apply Plus) All Classes
					Class 1	Classes 1½, 2, and 3	Loose Class 1, Free Class 1½	Medium Class 2	Close Class 3				Loose Class 1, Free Class 1½	Medium Class 2	Close Class 3		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
$\frac{1}{8}$	40	0.0250	0.1213	0.0043	0.1083	0.1090	0.0043	0.0029	0.0019	0.0930	0.1250	.01090	0.0043	0.0029	0.0019	0.0967	0.0053
$\frac{3}{16}$	24	0.0417	0.1813	0.0052	0.1596	0.1608	0.0052	0.0035	0.0023	0.1341	0.1875	0.1608	0.0052	0.0035	0.0023	0.1403	0.0071
$\frac{1}{4}$	20	0.0500	0.2426	0.0056	0.2166	0.2180	0.0058	0.0039	0.0026	0.1860	0.2500	0.2180	0.0058	0.0039	0.0026	0.1934	0.0096
$\frac{5}{16}$	18	0.0556	0.3043	0.0059	0.2753	0.2769	0.0063	0.0042	0.0028	0.2413	0.3125	0.2769	0.0063	0.0042	0.0028	0.2495	0.0099
$\frac{3}{8}$	16	0.0625	0.3658	0.0062	0.3332	0.3350	0.0068	0.0045	0.0030	0.2950	0.3750	0.3350	0.0068	0.0045	0.0030	0.3042	0.0103
$\frac{7}{16}$	14	0.0714	0.4269	0.0067	0.3898	0.3918	0.0073	0.0048	0.0032	0.3461	0.4375	0.3918	0.0073	0.0048	0.0032	0.3567	0.0107
$\frac{1}{2}$	12	0.0833	0.4877	0.0073	0.4442	0.4466	0.0077	0.0052	0.0034	0.3932	0.5000	0.4466	0.0077	0.0052	0.0034	0.4055	0.0114
$\frac{9}{16}$	12	0.0833	0.5502	0.0073	0.5067	0.5091	0.0080	0.0053	0.0036	0.4557	0.5625	0.5091	0.0080	0.0053	0.0036	0.4680	0.0114
$\frac{5}{8}$	11	0.0909	0.6116	0.0077	0.5642	0.5668	0.0084	0.0056	0.0037	0.5086	0.6250	0.5668	0.0084	0.0056	0.0037	0.5220	0.0118
$\frac{11}{16}$*	11	0.0909	0.6741	0.0077	0.6267	0.6293	0.0086	0.0058	0.0038	0.5711	0.6875	0.6293	0.0086	0.0058	0.0038	0.5845	0.0118
$\frac{3}{4}$	10	0.1000	0.7352	0.0082	0.6832	0.6860	0.0090	0.0060	0.0040	0.6220	0.7500	0.6860	0.0090	0.0060	0.0040	0.6368	0.0122
$\frac{7}{8}$	9	0.1111	0.8586	0.0088	0.8008	0.8039	0.0096	0.0064	0.0043	0.7328	0.8750	0.8039	0.0096	0.0064	0.0043	0.7492	0.0128

TABLE 15.—SCREW THREADS OF TRUNCATED WHITWORTH FORM—COARSE THREAD SERIES.—*Continued*

Size	Threads per Inch,	Pitch, $\frac{1}{n}$	Screw								Nut						
			Major Diameter Truncated		Pitch (Effective) Diameter					Minor Diam. Max.	Major Diam. Min.	Pitch (Effective) Diameter				Minor Diameter Truncated	
			Max.	Tolerance (Apply Minus) All Classes	Max.		Tolerance (Apply Minus)					Min.	Tolerance (Apply Plus)			Min.	Tolerance (Apply Plus) All Classes
					Class 1	Classes 1½, 2, and 3	Loose Class 1, Free Class 1½	Medium Class 2	Close Class 3				Loose Class 1, Free Class 1½	Medium Class 2	Close Class 3		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	8	0.1250	0.9815	0.0095	0.9165	0.9200	0.0102	0.0068	0.0045	0.8400	1.0000	0.9200	0.0102	0.0068	0.0045	0.8585	0.0135
1⅛	7	0.1429	1.1039	0.0104	1.0295	1.0335	0.0107	0.0072	0.0048	0.9420	1.1250	1.0335	0.0107	0.0072	0.0048	0.9631	0.0145
1¼	7	0.1429	1.2289	0.0104	1.1545	1.1585	0.0111	0.0074	0.0049	1.0670	1.2500	1.1585	0.0111	0.0074	0.0049	1.0881	0.0145
1½	6	0.1667	1.4754	0.0117	1.3886	1.3933	0.0120	0.0080	0.0053	1.2866	1.5000	1.3933	0.0120	0.0080	0.0053	1.3112	0.0157
1¾	5	0.2000	1.7204	0.0134	1.6162	1.6219	0.0129	0.0086	0.0057	1.4938	1.7500	1.6219	0.0129	0.0086	0.0057	1.5234	0.0174
2	4½	0.2222	1.9671	0.0146	1 8514	1.8577	0.0137	0.0091	0.0061	1.7154	2.0000	1.8577	0.0137	0.0091	0.0061	1.7483	0.0185
2¼	4	0.2500	2.2130	0.0160	2.0818	2.0899	0.0144	0.0096	0.0064	1.9298	2.2500	2.0899	0.0144	0.0096	0.0064	1.9668	0.0200
2½	4	0.2500	2.4630	0.0160	2.3328	2.3399	0.0149	0.0100	0.0066	2.1798	2.5000	2.3399	0.0149	0.0100	0.0066	2.2168	0.0200
2¾	3½	0.2857	2.7078	0.0179	2.5589	2.5670	0.0157	0.0104	0.0070	2.3840	2.7500	2.5670	0.0157	0.0104	0.0070	2.4262	0.0219
3	3½	0.2857	2.9578	0.0179	2.8089	2.8170	0.0161	0.0108	0.0072	2.6340	3.0000	2.8170	0.0161	0.0108	0.0072	2.6762	0.0219

NOTE 1. The tolerance on pitch diameter includes all variations in lead and angle. The values for pitch diameter tolerance given in this table are based on a length of engagement equal to the basic (major) diameter, but may be used for lengths of engagement up to 1½ diameters.

2. The minimum minor diameter of the screw is established by the crest of a new chaser (see F_s, Fig. 2*c*, left) and the maximum major diameter of the nut, by the crest of a new tap (see F_t, Fig. 2*c*, right).

* To be dispensed with wherever possible.

TABLE 16.—SCREW THREADS OF TRUNCATED WHITWORTH FORM—FINE THREAD SERIES
(Dimensions in Inches)

Size	Threads per Inch, n	Pitch, $\frac{1}{n}$	Screw								Nut						
			Major Diameter Truncated		Pitch (Effective) Diameter							Pitch (Effective) Diameter				Minor Diameter Truncated	
			Max.	Tolerance (Apply Minus) All Classes	Max.		Tolerance (Apply Minus)			Minor Diam. Max.	Major Diam. Min.	Min.	Tolerance (Apply Plus)			Min.	Tolerance (Apply Plus) All Classes
					Class 1	Classes 1½, 2, and 3	Loose Class 1, Free Class 1½	Medium Class 2	Close Class 3				Loose Class 1, Free Class 1½	Medium Class 2	Close Class 3		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
$\frac{3}{16}$	32	0.03125	0.1829	0.0046	0.1666	0.1675	0.0050	0.0033	0.0022	0.1475	0.1875	0.1675	0.0050	0.0033	0.0022	0.1521	0.0056
$\frac{7}{32}$	28	0.0357	0.2135	0.0049	0.1949	0.1959	0.0053	0.0036	0.0024	0.1730	0.2188	0.1959	0.0053	0.0036	0.0024	0.1783	0.0058
$\frac{1}{4}$	26	0.0385	0.2443	0.0050	0.2243	0.2254	0.0056	0.0037	0.0025	0.2008	0.2500	0.2254	0.0056	0.0037	0.0025	0.2065	0.0060
$\frac{9}{32}$	26	0.0385	0.2755	0.0050	0.2555	0.2566	0.0058	0.0039	0.0026	0.2320	0.2812	0.2566	0.0058	0.0039	0.0026	0.2377	0.0060
$\frac{5}{16}$	22	0.0455	0.3058	0.0054	0.2821	0.2834	0.0062	0.0041	0.0027	0.2543	0.3125	0.2834	0.0062	0.0041	0.0027	0.2610	0.0074
$\frac{3}{8}$	20	0.0500	0.3676	0.0056	0.3416	0.3430	0.0066	0.0044	0.0029	0.3110	0.3750	0.3430	0.0066	0.0044	0.0029	0.3184	0.0096
$\frac{7}{16}$	18	0.0556	0.4293	0.0059	0.4003	0.4019	0.0070	0.0047	0.0031	0.3663	0.4375	0.4019	0.0070	0.0047	0.0031	0.3745	0.0099
$\frac{1}{2}$	16	0.0625	0.4908	0.0062	0.4582	0.4600	0.0074	0.0050	0.0033	0.4200	0.5000	0.4600	0.0074	0.0050	0.0033	0.4292	0.0103
$\frac{9}{16}$	16	0.0625	0.5533	0.0062	0.5207	0.5225	0.0077	0.0052	0.0034	0.4825	0.5625	0.5225	0.0077	0.0052	0.0034	0.4917	0.0103
$\frac{5}{8}$	14	0.0714	0.6144	0.0067	0.5773	0.5793	0.0081	0.0054	0.0036	0.5336	0.6250	0.5793	0.0081	0.0054	0.0036	0.5442	0.0107
$\frac{11}{16}$	14	0.0714	0.6769	0.0067	0.6398	0.6418	0.0084	0.0056	0.0037	0.5961	0.6875	0.6418	0.0084	0.0056	0.0037	0.6067	0.0107
$\frac{3}{4}$	12	0.0833	0.7377	0.0073	0.6942	0.6966	0.0088	0.0059	0.0039	0.6432	0.7500	0.6966	0.0088	0.0059	0.0039	0.6555	0.0114

TABLE 16.—SCREW THREADS OF TRUNCATED WHITWORTH FORM—FINE THREAD SERIES.—*Continued*
(Dimensions in Inches)

Size	Threads per Inch, n	Pitch, $\frac{1}{n}$	Screw								Nut						
			Major Diameter Truncated		Pitch (Effective) Diameter					Minor Diam. Max.	Major Diam. Min.	Pitch (Effective) Diameter				Minor Diameter Truncated	
			Max.	Tolerance (Apply Minus) All Classes	Max.		Tolerance (Apply Minus)					Min.	Tolerance (Apply Plus)			Min.	Tolerance (Apply Plus) All Classes
					Class 1	Classes 1½, 2, and 3	Loose Class 1, Free Class 1½	Medium Class 2	Close Class 3				Loose Class 1, Free Class 1½	Medium Class 2	Close Class 3		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
13/16	12	0.0833	0.8002	0.0073	0.7567	0.7591	0.0090	0.0060	0.0040	0.7057	0.8125	0.7591	0.0090	0.0060	0.0040	.07180	0.0114
⅞	11	0.0909	0.8616	0.0077	0.8142	0.8168	0.0093	0.0062	0.0042	0.7586	0.8750	0.8168	0.0093	0.0062	0.0042	0.7720	0.0118
1	10	0.1000	0.9852	0.0082	0.9332	0.9360	0.0099	0.0066	0.0044	0.8720	1.0000	0.9360	0.0099	0.0066	0.0044	0.8868	0.0122
1⅛	9	0.1111	1.1086	0.0088	1.0508	1.0539	0.0104	0.0069	0.0046	0.9828	1.1250	1.0539	0.0104	0.0069	0.0046	0.9992	0.0128
1¼	9	0.1111	1.2336	0.0088	1.1758	1.1789	0.0108	0.0072	0.0048	1.1078	1.2500	1.1789	0.0108	0.0072	0.0048	1.1242	0.0128
1⅜	8	0.1250	1.3565	0.0095	1.2915	1.2950	0.0113	0.0075	0.0050	1.2150	1.3750	1.2950	0.0113	0.0075	0.0050	1.2335	0.0135
1½	8	0.1250	1.4815	0.0095	1.4165	1.4200	0.0116	0.0077	0.0052	1.3400	1.5000	1.4200	0.0116	0.0077	0.0052	1.3585	0.0135

NOTE: 1. The tolerance on pitch diameter includes all variations in lead and angle. The values for pitch diameter tolerances given in this table are based on a length of engagement equal to the basic (major) diameter, but may be used for lengths of engagement up to 1½ diameters.

2. The minimum minor diameter of the screw is established by the crest of a new chaser (see F_s, Fig. 2*c*, left) and the maximum major diameter of the nut, by the crest of a new tap (see F_t, Fig. 2*c*, right).

TABLE 17.—SCREW THREADS OF TRUNCATED WHITWORTH FORM—BRITISH STANDARD PIPE (PARALLEL)
(For General Engineering Purposes)
(Dimensions in Inches)

Size	Threads per Inch, n	Pitch, $\frac{1}{n}$	Screw							Nut						
			Major Diameter Truncated		Pitch (Effective) Diameter				Minor Diam. Max.	Major Diam. Min.	Pitch (Effective) Diameter				Minor Diameter Truncated	
			Max.	Tolerance (Apply Minus) All Classes	Max. All Classes	Tolerance (Apply Minus) Free Class 1½	Tolerance (Apply Minus) Medium Class 2	Tolerance (Apply Minus) Close Class 3			Min. All Classes	Tolerance (Apply Plus) Free Class 1½	Tolerance (Apply Plus) Medium Class 2	Tolerance (Apply Plus) Close Class 3	Min.	Tolerance (Apply Plus) All Classes
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
⅛	28	0.0357	0.3777	0.0049	0.3601	0.0064	0.0042	0.0028	0.3372	0.3830	0.3601	0.0064	0.0042	0.0028	0.3425	0.0058
¼	19	0.0526	0.5102	0.0057	0.4843	0.0073	0.0049	0.0032	0.4506	0.5180	0.4843	0.0073	0.0049	0.0032	0.4584	0.0097
⅜	19	0.0526	0.6482	0.0057	0.6223	0.0075	0.0050	0.0033	0.5886	0.6560	0.6223	0.0075	0.0050	0.0033	0.5964	0.0097
½	14	0.0714	0.8144	0.0067	0.7793	0.0084	0.0056	0.0037	0.7336	0.8250	0.7793	0.0084	0.0056	0.0037	0.7442	0.0107
⅝	14	0.0714	0.8914	0.0067	0.8563	0.0085	0.0056	0.0038	0.8106	0.9020	0.8563	0.0085	0.0056	0.0038	0.8212	0.0107
¾	14	0.0714	1.0304	0.0067	0.9953	0.0089	0.0060	0.0040	0.9496	1.0410	0.9553	0.0089	0.0060	0.0040	0.9602	0.0107
⅞	14	0.0714	1.1784	0.0067	1.1433	0.0091	0.0061	0.0040	1.0976	1.1890	1.1433	0.0091	0.0061	0.0040	1.1082	0.0107
1	11	0.0909	1.2956	0.0077	1.2508	0.0098	0.0065	0.0043	1.1926	1.3090	1.2508	0.0098	0.0065	0.0043	1.2060	0.0118
1¼	11	0.0909	1.6366	0.0077	1.5918	0.0103	0.0069	0.0046	1.5336	1.6500	1.5918	0.0103	0.0069	0.0046	1.5470	0.0118
1½	11	0.0909	1.8686	0.0077	1.8238	0.0107	0.0072	0.0048	1.7656	1.8820	1.8238	0.0107	0.0072	0.0048	1.7790	0.0118

NOTE: 1. The tolerance on pitch diameter includes all variations in lead and angle. The values for pitch diameter tolerances given in this table are based on a length of engagement equal to the basic major diameter, but may be used for lengths of engagement up to 1½ diameters.

2. The minimum minor diameter of the screw is established by the crest of a new chaser (see F_s, Fig. 2*c*, left) and the maximum major diameter of the nut by the crest of a new tap (see Fig. F_t, Fig. 2*c*, right).

TABLE 18.—SCREW THREADS OF TRUNCATED WHITWORTH FORM—SPECIAL THREAD SERIES

Pitch (Effective) Diameter Tolerances Include All Lead and Angle Errors
Recommended Pitches for Special Diameters and Lengths of Engagement
(Dimensions in Inches)

To obtain desired diameters, subtract values listed below from *basic* major diameter, as indicated, and use given tolerances.

Pitch (effective) diameter tolerances for Class 1 (Loose) and Class 1½ (Free), see.................... Table 24
For Class 2 (Medium), see.................... Table 25
For Class 3 (Close), see.................... Table 26

Threads per Inch, n	Pitch, $\frac{1}{n}$	Screw					Nut			
		Major Diameter Truncated		Pitch (Effective) Diameter Max.		Minor Diameter Max.	Major Diameter Min.	Pitch (Effective) Diameter Min.	Minor Diameter Truncated	
		Max.	Tolerance (Apply Minus)	Class 1	Classes 1½, 2, and 3				Min.	Tolerance (Apply Plus)
1	2	3	4	5	6	7	8	9	10	11
40	0.0250	0.0037	0.0043	......	0.0160	0.0320	0.0000	0.0160	0.0283	0.0053
36	0.0278	0.0041	0.0044	......	0.0178	0.0356	0.0000	0.0178	0.0315	0.0055
32	0.03125	0.0046	0.0046	......	0.0200	0.0400	0.0000	0.0200	0.0354	0.0056
28	0.0357	0.0053	0.0049	......	0.0229	0.0458	0.0000	0.0229	0.0405	0.0058
26	0.0385	0.0057	0.0050	0.0257	0.0246	0.0492	0.0000	0.0246	0.0436	0.0060
24	0.0417	0.0062	0.0052	0.0279	0.0267	0.0534	0.0000	0.0267	0.0472	0.0071
20	0.0500	0.0074	0.0056	0.0334	0.0320	0.0640	0.0000	0.0320	0.0566	0.0096
18	0.0556	0.0082	0.0059	0.0372	0.0356	0.0712	0.0000	0.0356	0.0629	0.0099
16	0.0625	0.0092	0.0062	0.0418	0.0400	0.0800	0.0000	0.0400	0.0708	0.0103
14	0.0714	0.0106	0.0067	0.0477	0.0457	0.0914	0.0000	0.0457	0.0809	0.0107
12	0.0833	0.0123	0.0073	0.0558	0.0534	0.1068	0.0000	0.0534	0.0944	0.0114
10	0.1000	0.0148	0.0082	0.0668	0.0640	0.1280	0.0000	0.0640	0.1133	0.0122
8	0.1250	0.0185	0.0095	0.0835	0.0800	0.1600	0.0000	0.0800	0.1416	0.0135
6	0.1667	0.0246	0.0117	0.1114	0.1067	0.2134	0.0000	0.1067	0.1888	0.0157
4	0.2500	0.0370	0.0160	0.1672	0.1601	0.3202	0.0000	0.1601	0.2832	0.0200

NOTE: 1. The tolerance on pitch (effective) diameter includes all variations in lead and angle. The values for pitch (effective) diameter tolerances given in this table are based on a length of engagement equal to the basic (major) diameter, but may be used for lengths of engagement up to 1½ diameters.

2. The minimum minor diameter of the screw is established by the crest of a new chaser (see F_s, Fig. 2c, left) and the maximum major diameter of the nut by the crest of a new tap (see F_t, Fig. 2c, right).

TABLE 19.—WHITWORTH SCREW THREADS OF SPECIAL DIAMETERS, PITCHES, AND LENGTHS OF ENGAGEMENT
Pitch (Effective) Diameter Tolerances
Classes 1 (Loose) and 1½ (Free)
(Dimensions in Inches)

Threads per Inch	Lengths of Engagement		Pitch Diameter Tolerances for Diameters Up to and Including											
	From	To and Including	1/4	1/2	3/4	1 1/4	2	3	4	6	8	11	15	20
26 24	1/4	3/8	0.0058	0.0062	0.0066	0.0070	0.0076	0.0081						
	3/8	1/2	0.0062	0.0067	0.0071	0.0075	0.0080	0.0086						
	1/2	3/4	0.0068	0.0073	0.0077	0.0081	0.0086							
	3/4	1		0.0079	0.0083	0.0087								
20	1/4	3/8		0.0064	0.0068	0.0072	0.0077	0.0083						
	3/8	1/2		0.0068	0.0072	0.0077	0.0082	0.0087						
	1/2	3/4		0.0074	0.0078	0.0082	0.0088	0.0093						
	3/4	1		0.0080	0.0085	0.0089	0.0094	0.0100						
18 16	1/4	3/8		0.0066	0.0070	0.0074	0.0079	0.0085	0.0089	0.0095				
	3/8	1/2		0.0070	0.0074	0.0079	0.0084	0.0089	0.0094	0.0100				
	1/2	3/4		0.0076	0.0080	0.0084	0.0090	0.0095	0.0100	0.0106				
	3/4	1		0.0082	0.0086	0.0091	0.0096	0.0102	0.0106					
	1	1 1/2		0.0091	0.0095	0.0099	0.0104	0.0110						
14 12	3/8	1/2			0.0077	0.0081	0.0087	0.0092	0.0097	0.0103				
	1/2	3/4			0.0083	0.0087	0.0092	0.0098	0.0103	0.0109				
	3/4	1			0.0089	0.0094	0.0099	0.0104	0.0109	0.0115				
	1	1 1/2			0.0098	0.0102	0.0107	0.0113	0.0118	0.0123				
	1 1/2	2				0.0111	0.0116	0.0122	0.0127	0.0132				

TABLE 19.—WHITWORTH SCREW THREADS OF SPECIAL DIAMETERS, PITCHES, AND LENGTHS OF ENGAGEMENT.—*Continued*

Threads per Inch	Lengths of Engagement		Pitch Diameter Tolerances for Diameters Up to and Including											
	From	To and Including	¼	½	¾	1½	2	3	4	6	8	11	15	20
10	⅜	½				0.0083	0.0089	0.0094	0.0099	0.0105	0.0111			
	½	¾				0.0089	0.0095	0.0100	0.0105	0.0111	0.0117			
	¾	1				0.0096	0.0101	0.0107	0.0111	0.0117	0.0123			
	1	1½				0.0104	0.0109	0.0115	0.0120	0.0125	0.0131			
	1½	2				0.0113	0.0119	0.0124	0.0129	0.0135	0.0141			
8	½	¾				0.0092	0.0097	0.0103	0.0108	0.0113	0.0119	0.0126		
	¾	1				0.0099	0.0104	0.0109	0.0114	0.0120	0.0126	9.0132		
	1	1½				0.0107	0.0112	0.0118	0.0122	0.0128	0.0134	0.0140		
	1½	2				0.0116	0.0121	0.0127	0.0132	0.0137	0.0143	0.0150		
	2	3				0.0128	0.0133	0.0138	0.0143	0.0149	0.0155			
6	¾	1					0.0108	0.0113	0.0118	0.0124	0.0130	0.0136	0.0143	
	1	1½					0.0116	0.0122	0.0126	0.0132	0.0138	0.0144	0.0151	
	1½	2					0.0125	0.0131	0.0136	0.0141	0.0148	0.0154	0.0161	
	2	3					0.0137	0.0142	0.0147	0.0153	0.0159	0.0165	0.0172	
	3	4					6.0150	0.0156	0.0160	0.0166	0.0172	0.0178		
4	1	1½						0.0129	0.0133	0.0139	0.0145	0.0151	0.0158	0.0166
	1½	2						0.0138	0.0143	0.0148	0.0154	0.0161	0.0168	0.0175
	2	3						0.0149	0.0154	0.0160	0.0166	0.0172	0.0179	0.0187
	3	4						0.0162	0.0167	0.0173	0.0179	0.0185	0.0192	0.0200
	4	6						0.0179	0.0184	0.0189	0.0196	0.0202	0.0209	0.0216

TABLE 20.—WHITWORTH SCREW THREADS OF SPECIAL DIAMETERS, PITCHES, AND LENGTHS OF ENGAGEMENT

Pitch (Effective) Diameter Tolerances
Class 2 (Medium)
(Dimensions in Inches)

Threads per Inch	Lengths of Engagement		Pitch Diameter Tolerances for Diameters Up to and Including											
	From	To and Including	¼	½	¾	1¼	2	3	4	6	8	11	15	20
40 36	⅛	¼	0.0033	0.0036	0.0038	0.0041	0.0045							
	¼	⅜	0.0037	0.0040	0.0042	0.0045	0.0049							
	⅜	½	0.0040	0.0043	0.0045	0.0048								
32 28	⅛	¼	0.0034	0.0037	0.0040	0.0042	0.0046							
	¼	⅜	0.0036	0.0041	0.0043	0.0046	0.0050							
	⅜	½	0.0041	0.0044	0.0046	0.0049	0.0053							
	½	¾	0.0045	0.0048	0.0050	0.0053								
26 24	¼	⅜	0.0038	0.0041	0.0044	0.0047	0.0050	0.0054						
	⅜	½	0.0041	0.0044	0.0047	0.0050	0.0054	0.0057						
	½	¾	0.0045	0.0048	0.0051	0.0054	0.0057							
	¾	1		0.0053	0.0055	0.0058								
20	¼	⅜		0.0042	0.0045	0.0048	0.0051	0.0055						
	⅜	½		0.0045	0.0048	0.0051	0.0055	0.0058						
	½	¾		0.0049	0.0052	0.0055	0.0058	0.0062						
	¾	1		0.0054	0.0056	0.0059	0.0063	0.0066						

18 16	¼	⅜		0.0044	0.0046	0.0049	0.0053	0.0056	0.0060	0.0063				
	⅜	½		0.0047	0.0049	0.0052	0.0056	0.0059	0.0063	0.0067				
	½	¾		0.0051	0.0053	0.0056	0.0060	0.0063	0.0067	0.0070				
	¾	1		0.0055	0.0058	0.0061	0.0064	0.0068	0.0071					
	1	1½		0.0060	0.0063	0.0066	0.0070	0.0073						
14 12	⅜	½			0.0051	0.0054	0.0058	0.0061	0.0065	0.0068				
	½	¾			0.0055	0.0058	0.0062	0.0065	0.0069	0.0072				
	¾	1			0.0060	0.0062	0.0066	0.0070	0.0073	0.0077				
	1	1½			0.0065	0.0068	0.0071	0.0075	0.0078	0.0082				
	1½	2				0.0074	0.0078	0.0081	0.0084	0.0088				
10	⅜	½				0.0056	0.0059	0.0063	0.0066	0.0070	0.0074			
	½	¾				0.0060	0.0063	0.0067	0.0070	0.0074	0.0078			
	¾	1				0.0064	0.0067	0.0071	0.0074	0.0078	0.0082			
	1	1½				0.0069	0.0073	0.0076	0.0080	0.0084	0.0088			
	1½	2				0.0076	0.0079	0.0083	0.0086	0.0090	0.0094			
8	½	¾				0.0061	0.0065	0.0069	0.0072	0.0076	0.0080	0.0084		
	¾	1				0.0066	0.0069	0.0073	0.0076	0.0080	0.0084	0.0088		
	1	1½				0.0071	0.0075	0.0078	0.0082	0.0085	0.0089	0.0094		
	1½	2				0.0077	0.0081	0.0085	0.0088	0.0092	0.0096	0.0100		
	2	3				0.0085	0.0089	0.0092	0.0095	0.0099	0.0103			
6	¾	1					0.0072	0.0076	0.0079	0.0083	0.0087	0.0091	0.0096	
	1	1½					0.0077	0.0081	0.0084	0.0088	0.0092	0.0096	0.0101	
	1½	2					0.0084	0.0087	0.0090	0.0094	0.0098	0.0102	0.0107	
	2	3					0.0091	0.0095	0.0098	0.0102	0.0106	0.0110	0.0115	
	3	4					0.0100	0.0104	0.0107	0.0111	0.0115	0.0119		
4	1	1½						0.0086	0.0089	0.0093	0.0097	0.0101	0.0106	0.0110
	1½	2						0.0092	0.0095	0.0099	0.0103	0.0107	0.0112	0.0117
	2	3						0.0100	0.0103	0.0107	0.0111	0.0115	0.0119	0.0124
	3	4						0.0108	0.0111	0.0115	0.0119	0.0123	0.0128	0.0133
	4	6						0.0119	0.0122	0.0126	0.0130	0.0134	0.0139	0.0144

TABLE 21.—WHITWORTH SCREW THREADS OF SPECIAL DIAMETERS, PITCHES, AND LENGTHS OF ENGAGEMENT
Pitch (Effective) Diameter Tolerances
Class 3 (Close)
(Dimensions in Inches)

Threads per Inch	Lengths of Engagement		Pitch Diameter Tolerances for Diameters Up to and Including											
	From	To and Including	1/4	1/2	3/4	1 1/2	2	3	4	6	8	11	15	20
40 36	1/8	1/4	0.0022	0.0024	0.0026	0.0028	0.0030							
	1/4	3/8	0.0024	0.0026	0.0028	0.0030	0.0032							
	3/8	1/2	0.0026	0.0028	0.0030	0.0032								
32 28	1/8	1/4	0.0023	0.0025	0.0026	0.0028	0.0031							
	1/4	3/8	0.0025	0.0027	0.0029	0.0031	0.0033							
	3/8	1/2	0.0027	0.0029	0.0031	0.0033	0.0035							
	1/2	3/4	0.0030	0.0032	0.0034	0.0035								
26 24	1/4	3/8	0.0026	0.0028	0.0029	0.0031	0.0034	0.0036						
	3/8	1/2	0.0028	0.0030	0.0031	0.0033	0.0036	0.0038						
	1/2	3/4	0.0030	0.0032	0.0034	0.0036	0.0038							
	3/4	1		0.0035	0.0037	0.0039								
20	1/4	3/8		0.0028	0.0030	0.0032	0.0034	0.0037						
	3/8	1/2		0.0030	0.0032	0.0034	0.0036	0.0039						
	1/2	3/4		0.0033	0.0035	0.0037	0.0039	0.0041						
	3/4	1		0.0036	0.0038	0.0039	0.0042	0.0044						

	1/4	3/8		0.0029	0.0031	0.0033	0.0035	0.0038	0.0040	0.0042			
	3/8	1/2		0.0031	0.0033	0.0035	0.0037	0.0040	0.0042	0.0044			
18	1/2	3/4		0.0034	0.0036	0.0037	0.0040	0.0042	0.0044	0.0047			
16	3/4	1		0.0037	0.0038	0.0040	0.0043	0.0045	0.0047				
	1	1 1/2		0.0040	0.0042	0.0044	0.0046	0.0049					
	3/8	1/2			0.0034	0.0036	0.0039	0.0041	0.0043	0.0046			
	1/2	3/4			0.0037	0.0039	0.0041	0.0044	0.0046	0.0048			
14	3/4	1			0.0040	0.0042	0.0044	0.0046	0.0049	0.0051			
12	1	1 1/2			0.0043	0.0045	0.0048	0.0050	0.0052	0.0055			
	1 1/2	2				0.0049	0.0052	0.0054	0.0056	0.0059			
										0.0055			
	3/8	1/2				0.0037	0.0039	0.0042	0.0044	0.0047	0.0049		
	1/2	3/4				0.0040	0.0042	0.0044	0.0047	0.0049	0.0052		
10	3/4	1				0.0043	0.0045	0.0047	0.0049	0.0052	0.0055		
	1	1 1/2				0.0046	0.0049	0.0051	0.0053	0.0056	0.0058		
	1 1/2	2				0.0050	0.0053	0.0055	0.0057	0.0060	0.0063		
	1/2	3/4				0.0041	0.0043	0.0046	0.0048	0.0050	0.0053	0.0056	
	3/4	1				0.0044	0.0046	0.0049	0.0051	0.0053	0.0056	0.0059	
8	1	1 1/2				0.0047	0.0050	0.0052	0.0054	0.0057	0.0060	0.0062	
	1 1/2	2				0.0052	0.0054	0.0056	0.0059	0.0061	0.0064	0.0066	
	2	3				0.0057	0.0059	0.0062	0.0064	0.0066	0.0069		
	3/4	1					0.0048	0.0050	0.0053	0.0055	0.0058	0.0061	0.0064
	1	1 1/2					0.0052	0.0054	0.0056	0.0059	0.0061	0.0064	0.0067
6	1 1/2	2					0.0056	0.0058	0.0060	0.0063	0.0066	0.0068	0.0071
	2	3					0.0061	0.0063	0.0065	0.0068	0.0071	0.0073	0.0077
	3	4					0.0067	0.0069	0.0071	0.0074	0.0077	0.0079	
	1	1 1/2						0.0057	0.0059	0.0062	0.0065	0.0067	0.0070	0.0074
	1 1/2	2						0.0061	0.0063	0.0066	0.0069	0.0071	0.0074	0.0078
4	2	3						0.0066	0.0069	0.0071	0.0074	0.0077	0.0080	0.0083
	3	4						0.0072	0.0074	0.0077	0.0080	0.0082	0.0085	0.0089
	4	6						0.0079	0.0082	0.0084	0.0087	0.0090	0.0093	0.0096

TABLE 21a.—INSPECTION GAGE DATA FOR SCREW THREADS OF TRUNCATED WHITWORTH FORM

Screw	Detail	Found in Table 28 Column
Plain Adjustable Snap Gage		
Major diameter go gage = maximum major diameter of screw	Tolerance minus	13
Major diameter not-Go gage = minimum major diameter of screw	Tolerance plus	13
Go Thread Ring Gage		
Major diameter	Cleared	3
Pitch (effective) diameter	Set to check	
Minor diameter		
Maximum minor diameter of screw. (Check with plain check plug where dimension measured is less than ¼ inch)	Tolerance minus	12
Lead	Allowable variation, plus or minus	7
Half angle	Tolerance, plus or minus	8
Thread Check for Go Ring Gage		
Major diameter = maximum major diameter of screw	Tolerance minus	12
Pitch (effective) diameter = maximum pitch (effective) diameter of screw	Allowance minus Tolerance minus	9 10 or 11
Minor diameter	Cleared	5
Lead, allowable variation (Same as for gage checked)		
Half angle, tolerance (Same as for gage checked)		
Plain Check for Go Ring Gage (Used where dimension measured is less than ¼ inch)		
Limits (Same as for minor diameter of gage checked.)		
Not-Go Thread Ring Gage		
Major diameter	Cleared	4
Pitch (effective) diameter	Set to check	
Minor diameter = minimum pitch (effective) diameter of screw minus $\frac{p}{3}$ (Check with plain check plug when dimension measured is less than ¼ inch)	Determine $\frac{p}{3}$ from Tolerance plus	6 12
Lead	Allowable variation, plus or minus	7
Half angle	Tolerance, plus or minus	8
Thread Check for Not-Go Ring Gage		
*Major diameter = *maximum major diameter of screw	Tolerance plus	12
Pitch (effective) diameter = minimum pitch diameter of screw	Tolerance plus	11
Minor diameter	Cleared	4
Lead, allowable variation (Same as gage checked)		
Half angle, tolerance (Same as gage checked)		
Plain Check for Not-Go Ring Gage (Used where dimension measured is less than ¼ inch)		
Diameter and limits same as for minor diameter of gage checked		

TABLE 21*a*.—INSPECTION GAGE DATA FOR SCREW THREADS OF TRUNCATED WHITWORTH FORM.—*Continued*

Nut	Detail	Found in Table 28 Column
Go Thread Plug Gage		
Major diameters = minimum major diameter of nut	Tolerance plus	12
Pitch (effective) diameter = minimum effective (pitch) diameter of nut	Allowance plus Tolerance plus	9 10 or 11
Minor diameter	Cleared	3
Lead	Allowable variation, plus or minus	7
Half angle	Tolerance, plus or minus	8
Not-Go Thread Plug Gage		
Major diameter = maximum effective (pitch) diameter of nut plus $\frac{p}{3}$	Determine $\frac{p}{3}$ from Tolerance minus	6 12
Pitch (effective) diameter = maximum effective (pitch) diameter of nut	Tolerance minus	11
Minor diameter	Cleared	4
Lead	Allowable variation, plus or minus	7
Half angle	Tolerance, plus or minus	8
Go Plain Plug Gage		
Minor diameter = minimum minor diameter of nut	Allowance plus Tolerance plus	9 14
Not-Go Plain Plug Gage		
Minor diameter = maximum minor diameter of nut	Tolerance minus	14

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* Except that crest of thread shall never have a flat of less than 0.003 inch.

TABLE 22.—SCREW THREADS OF TRUNCATED WHITWORTH FORM—PLAIN AND THREAD INSPECTION GAGES (Dimensions in Inches)

Threads per Inch	Pitch	Root Clearance Width[1]			$\frac{p}{3}$			Allowance	Pitch (Effective) Diameter			Plain Gages Tolerances	
		0.2436p	$\frac{p}{3}$	$\frac{p}{6}$	For diameter at Crest of Not Go Gage, Apply Value to Pitch (Effective) Diameter	Lead, Available Variation	Half Angle Tolerance, All Thread Gages	See Note[2]	Tolerance		Major Diam. Thread Plugs and Minor Diam. Thread Rings—All Classes—Tolerance for Go and Not Go	Screws, All Classes	Nuts, All Classes
		Go Thread Plugs, Rings	Not Go Thread Plugs, Rings, and Checks	Go Thread Ring Checks					Classes 1, 1½ and 2 Go Only	Class 3 Go and Classes 1, 1½, 2 and 3 Not Go		Major Diameter	Minor Diam. to 3 Inches Inclusive[3]
												Adjustable Snap Go and Not Go	Go and Not Go
1	2	3	4	5	6	7	8	9	10	11	12	13	14
							deg. min.						
40	0.025000	0.006	0.008	0.004	0.0083	0.0002	0 30	0.0001	0.0003	0.0002	0.0004	0.0002	0.00015
36	0.027778	0.007	0.009	0.005	0.0093	0.0002	0 30	0.0001	0.0003	0.0002	0.0004	0.0002	0.00015
32	0.031250	0.008	0.010	0.005	0.0104	0.0003	0 20	0.0001	0.0003	0.0003	0.0004	0.0002	0.00015

28	0.035714	0.009	0.012	0.006	0.0119	0.0003	0	20	0.0002	0.0003	0.0003	0.0005	0.0002	0.0002
26	0.038462	0.009	0.013	0.006	0.0128	0.0003	0	20	0.0002	0.0003	0.0003	0.0005	0.0002	0.0002
24	0.041667	0.010	0.014	0.007	0.0139	0.0003	0	20	0.0002	0.0003	0.0003	0.0005	0.0002	0.0002
22	0.045455	0.011	0.015	0.008	0.0152	0.0003	0	20	0.0002	0.0003	0.0003	0.0005	0.0002	0.0002
20	0.050000	0.012	0.017	0.008	0.0167	0.0003	0	20	0.0002	0.0003	0.0003	0.0005	0.0002	0.0002
18	0.055556	0.014	0.019	0.009	0.0185	0.0003	0	15	0.0002	0.0003	0.0003	0.0005	0.0002	0.0002
16	0.062500	0.015	0.021	0.010	0.0208	0.0003	0	15	0.0002	0.0004	0.0003	0.0006	0.0002	0.0002
14	0.071429	0.017	0.024	0.012	0.0238	0.0003	0	15	0.0002	0.0004	0.0003	0.0006	0.0002	0.0002
12	0.083333	0.020	0.028	0.014	0.0278	0.0003	0	10	0.0002	0.0004	0.0003	0.0006	0.0003	0.0003
11	0.090909	0.022	0.030	0.015	0.0303	0.0003	0	10	0.0002	0.0004	0.0003	0.0006	0.0003	0.0003
10	0.100000	0.024	0.033	0.017	0.0333	0.0003	0	10	0.0002	0.0004	0.0003	0.0006	0.0003	0.0003
9	0.111111	0.027	0.037	0.019	0.0370	0.0003	0	10	0.0002	0.0005	0.0003	0.0007	0.0003	0.0003
8	0.125000	0.030	0.042	0.021	0.0417	0.0004	0	5	0.0002	0.0005	0.0004	0.0007	0.0004	0.0003
7	0.142857	0.035	0.048	0.024	0.0476	0.0004	0	5	0.0002	0.0005	0.0004	0.0007	0.0004	0.0003
6	0.166667	0.041	0.056	0.028	0.0556	0.0004	0	5	0.0003	0.0005	0.0004	0.0008	0.0005	0.0004
5	0.200000	0.049	0.067	0.033	0.0667	0.0004	0	5	0.0003	0.0005	0.0004	0.0008	0.0005	0.0004
4½	0.222222	0.054	0.074	0.037	0.0741	0.0004	0	5	0.0003	0.0005	0.0004	0.0008	0.0005	0.0004
4	0.250000	0.061	0.083	0.042	0.0833	0.0004	0	5	0.0003	0.0006	0.0004	0.0009	0.0005	0.0004
3½	0.285714	0.070	0.095	0.048	0.0952	0.0004	0	5	0.0003	0.0006	0.0004	0.0009	0.0005	0.0004

---

[1] Root clearance may be sharp V, but in all cases must clear the crest of the thread being measured.

[2] This inspection gage allowance applies to favor wear to pitch diameter of go thread gages only of Classes 1, 1½, and 2 and to go plain plugs of all classes for minor diameter of nuts. When work gages are used, this allowance shall be applied to favor wear for all classes.

[3] For diameters over 3 inches, add 0.0001 inch for each additional 2 inches or fraction thereof.

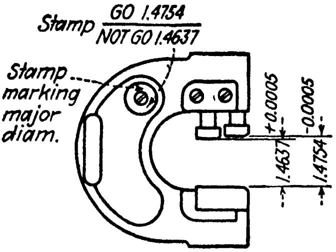

FIG. 2*e*.—Adjustable Plain Snap Gage (American Gage Design Standard, Model C) for Checking Screw Threads of Truncated Whitworth Form. Nominal Diameter 1½ Inches; 6 Threads per Inch; Class 2 Tolerance.

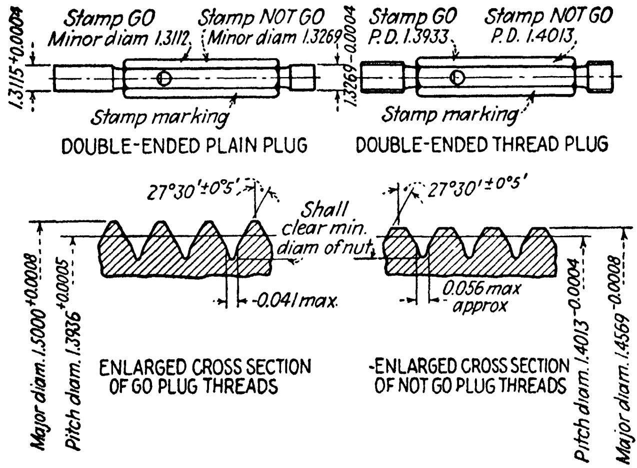

FIG. 2*f*.—Double-Ended Plain and Thread Plug Gages for Checking Screw Threads of Truncated Whitworth Form. Nominal Diameter 1½ Inches; 6 Threads per Inch; Class 2 Tolerance.

NOTES. Gages are to be of American Gage Design Standard. Gaging members are to be hardened, ground, and lapped. First half-turn of end threads is to be removed to avoid feather edges. Permissible variation in lead between any two threads ± 0.0004 inch.

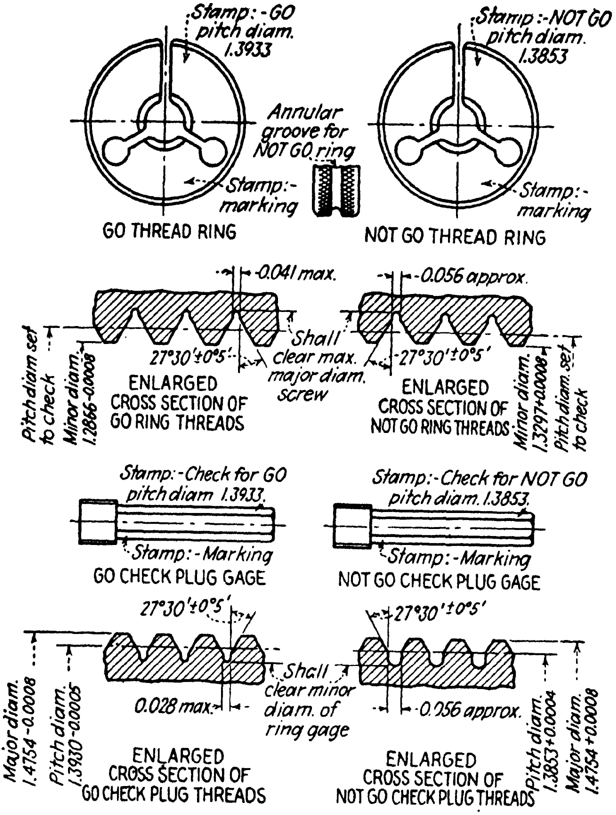
Stamp:-GO pitch diam. 1.3933
Annular groove for NOT GO ring
Stamp:-marking
GO THREAD RING
Stamp:-NOT GO pitch diam. 1.3853
Stamp:-marking
NOT GO THREAD RING
0.041 max.
27°30'±0°5'
Shall clear max. major diam. screw
ENLARGED CROSS SECTION OF GO RING THREADS
Pitch diam set to check
Minor diam. 1.2866-0.0008
0.056 approx.
27°30'±0°5'
ENLARGED CROSS SECTION OF NOT GO RING THREADS
Minor diam. 1.3297+0.0008
Pitch diam. set to check
Stamp:-Check for GO pitch diam 1.3933.
Stamp:-Marking
GO CHECK PLUG GAGE
Stamp:-Check for NOT GO pitch diam. 1.3853.
Stamp:-Marking
NOT GO CHECK PLUG GAGE
27°30'±0°5'
Shall clear minor diam. of ring gage
0.028 max.
Major diam. 1.4754-0.0008
Pitch diam. 1.3930-0.0005
ENLARGED CROSS SECTION OF GO CHECK PLUG THREADS
27°30'±0°5'
0.056 approx.
Pitch diam. 1.3853+0.0004
Major diam. 1.4754+0.0008
ENLARGED CROSS SECTION OF NOT GO CHECK PLUG THREADS

FIG. 2g.

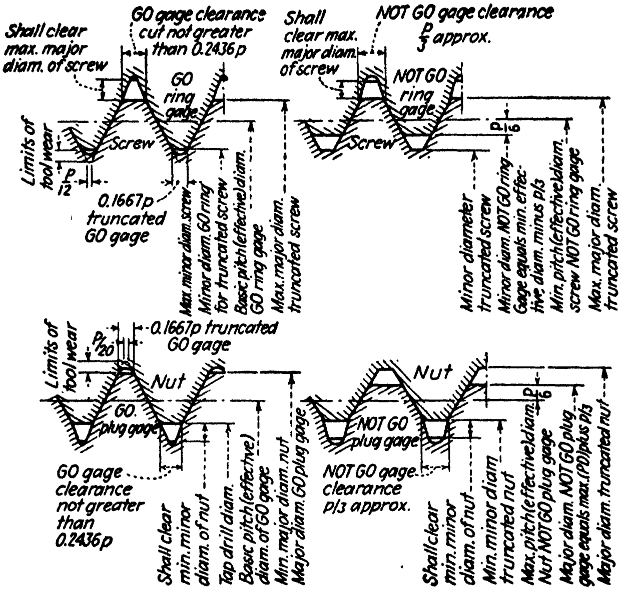
GO gage clearance cut not greater than 0.2436p
Shall clear max. major diam. of screw
GO ring gage
Screw
Limits of tool wear
p/12
0.1667p truncated GO gage
Max. minor diam. screw
Minor diam. GO ring for truncated screw
Basic pitch (effective) diam. GO ring gage
Max. major diam. truncated screw
Shall clear max. major diam. of screw
NOT GO gage clearance p/3 approx.
NOT GO ring gage
Screw
p/6
Minor diameter truncated screw
Minor diam. NOT GO ring Gage equals min. effective diam. minus p/3
Min. pitch (effective) diam. screw NOT GO ring gage
Max. major diam. truncated screw
Limits of tool wear
p/20
0.1667p truncated GO gage
Nut
GO plug gage
GO gage clearance not greater than 0.2436p
Shall clear min. minor diam. of nut
Tap drill diam.
Basic pitch (effective) diam. of GO gage
Min. major diam. nut
Major diam. GO plug gage
Nut
NOT GO plug gage
NOT GO gage clearance p/3 approx.
p/6
Shall clear min. minor diam. of nut
Min. minor diam. truncated nut
Max. pitch (effective) diam. Nut NOT GO plug gage
Major diam. NOT GO plug gage equals max. (PD) plus p/3
Major diam. truncated nut

FIG. 2h.

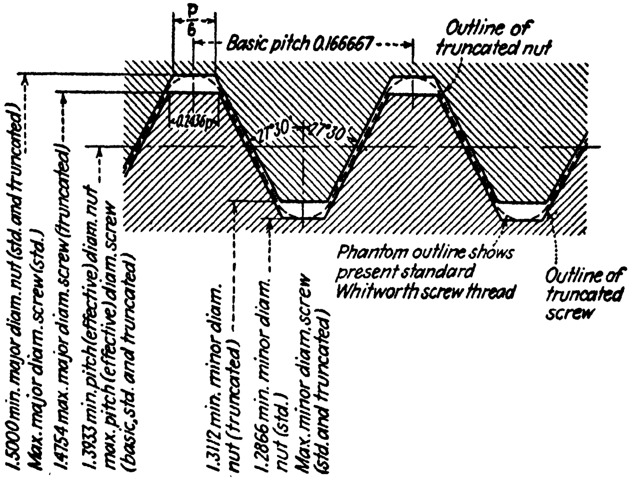
P/6
Basic pitch 0.166667
Outline of truncated nut
0.1436p
27°30'
27°30'
1.5000 min. major diam. nut (std. and truncated)
Max. major diam. screw (std.)
1.4754 max. major diam. screw (truncated)
1.3933 min. pitch (effective) diam. nut
max. pitch (effective) diam. screw
(basic, std. and truncated)
1.3112 min. minor diam. nut (truncated)
1.2866 min. minor diam. nut (std.)
Max. minor diam. screw (std. and truncated)
Phantom outline shows present standard Whitworth screw thread
Outline of truncated screw

FIG. 2*i*.—Example of Screw Threads of Truncated Whitworth Form, Coarse Series Nominal Diameter 1½ Inches; 6 Threads per Inch; Class 2 Tolerance; Length of Engagement 1½ Inches.

NOTE. In this drawing clearance has been shown between the pitches for the purpose of accentuating the outline of the thread forms. However, under maximum metal conditions the full length of the flanks of any combination of the four units is in metal-to-metal contact.

TRUNCATED WHITWORTH FORM
Nominal Diameter 1½ Inches; Length of Engagement 1½ Inches; 6 Threads per Inch; Class 2 (Medium) Tolerance

Dimensions of Thread on Screw		Dimensions of Thread in Nut	
Major diameter	1.4754 − 0.0117	Major diameter	1.5000 minimum
Pitch (effective) diameter	1.3933 − 0.0080	Pitch (effective) diameter	1.3933 + 0.0080
Minor diameter	1.2866 maximum	Minor diameter	1.3112 + 0.0157

COMPARATIVE DIMENSIONS OF STANDARD WHITWORTH FORM
Nominal Diameter 1½ Inches; Length of Engagement 1½ Inches; 6 Threads per Inch; Medium Fit

Dimensions of Thread on Screw		Dimensions of Thread in Nut	
Major diameter	1.5000 − 0.0121	Major diameter	1.5000 minimum
Pitch (effective) diameter)	1.3933 − 0.1080	Pitch (effective) diameter	1.3933 + 0.0080
Minor diameter	1.2866 − 0.0162	Minor diameter	1.2866 + 0.0403

TABLE 23.—SUGGESTED TAP DRILL SIZES*
Screw Threads of Truncated Whitworth Form—Coarse Series

Nominal Thread Size	Minor Diam. of Nut, in Inches		Stock Drill	
	Min.	Max.	Designation	Decimal Size, in Inches
$\frac{1}{8}$-40	0.0967	0.1020	No. 40	0.0980
			2.5 mm	0.0984
			No. 39	0.0995
$\frac{3}{16}$-24	0.1403	0.1474	No.28	0.1405
			$\frac{9}{64}$ in.	0.1406
			3.6 mm	0.1417
			No. 27	0.1440
			3.7 mm	0.1457
$\frac{1}{4}$-20	0.1934	0.2030	No. 10	0.1935
			No. 9	0.1960
			5 mm	0.1968
			No. 8	0.1990
			5.1 mm	0.2008
			No. 7	0.2010
$\frac{5}{16}$-18	0.2495	0.2594	$\frac{1}{4}$ in.	0.2500
			6.4 mm	0.2520
			6.5 mm	0.2559
			F	0.2570
$\frac{3}{8}$-16	0.3042	0.3145	7.75 mm	0.3051
			7.8 mm	0.3071
			7.9 mm	0.3110
			$\frac{5}{16}$ in.	0.3125
$\frac{7}{16}$-14	0.3567	0.3674	T	0.3580
			9.1 mm	0.3583
			$\frac{23}{64}$ in.	0.3594
			9.2 mm	0.3622
			9.25 mm	0.3642
$\frac{1}{2}$-12	0.4055	0.4169	$\frac{13}{32}$ in.	0.4062
			Z	0.4130
			10.5 mm	0.4134
$\frac{9}{16}$-12	0.4680	0.4794	$\frac{15}{32}$ in.	0.4688
			12 mm	0.4724
$\frac{5}{8}$-11	0.5220	0.5338	$\frac{17}{32}$ in.	0.5312
			13.5 mm	0.5315
$\frac{11}{16}$-11	0.5845	0.5963	15 mm	0.5906
			$\frac{19}{32}$ in.	0.5938

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* This table is for reference only. It may be that, due to unfavorable manufacturing conditions, the use of a drill given in this list will not result in the production of minor diameters lying within the specified maximum and minimum limits.

TABLE 23a.—SUGGESTED TAP DRILL SIZES.*—*Continued*

Nominal Thread Size	Minor Diam. of Nut, in Inches		Stock Drill	
	Min.	Max.	Designation	Decimal Size, in Inches
⅝-10	0.6368	0.6490	41/64 in.	0.6406
⅞-9	0.7492	0.7620	¾ in.	0.7500
1-8	0.8585	0.8720	55/64 in.	0.8594
			22 mm	0.8661
1⅛-7	0.9631	0.9776	24.5 mm	0.9646
			31/32 in.	0.9688
1¼-7	1.0881	1.1026	1 3/32 in.	1.0938
			28 mm	1.1024
1½-6	1.3112	1.3269	1 5/16 in.	1.3125
			33.5 mm	1.3189
1¾-5	1.5234	1.5408	1 17/32 in.	1.5312
			39 mm	1.5354
2-4½	1.7483	1.7668	1¾ in.	1.7500
			44.5 mm	1.7520
			1 49/64 in.	1.7656
2¼-4	1.9668	1.9868	50 mm	1.9685
			1 31/32 in.	1.9688
			1 63/64 in.	1.9844
2½-4	2.2168	2.2368	2 7/32 in.	2.2188
			56.5 mm	2.2244
			2 15/64 in.	2.2344
2¾-3½	2.4262	2.4481	2 7/16 in.	2.4375
			62 mm	2.4409
3-3½	2.6762	2.6981	68 mm	2.6772
			2 11/16 in.	2.6875
			68.5 mm	2.6968

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* This table is for reference only. It may be that, due to unfavorable manufacturing conditions, the use of a drill given in this list will not result in the production of minor diameters lying within the specified maximum and minimum limits.

TABLE 24.—SUGGESTED TAP DRILL SIZES*
Screw Threads of Truncated Whitworth Form—Fine Series

Nominal Thread Size	Minor Diam. of Nut, in Inches		Stock Drill	
	Min.	Max.	Designation	Decimal Size, in Inches
3/16-32	0.1521	0.1577	No. 24	0.1520
			3.9 mm	0.1535
			No. 23	0.1540
			5/32 in.	0.1562
7/32-8	0.1783	0.1841	No. 15	0.1800
			4.6 mm	0.1811
			No. 14	0.1820
1/4-26	0.2065	0.2125	5.25 mm	0.2067
			5.3 mm	0.2087
			No. 4	0.2090
9/32-26	0.2377	0.2437	B	0.2380
			6.1 mm	0.2402
			C	0.2420
5/16-22	0.2610	0.2684	G	0.2610
			6.7 mm	0.2638
			17/64 in.	0.2656
			6.75 mm	0.2657
			H	0.2660
3/8-20	0.3184	0.3280	8.1 mm	0.3189
			8.2 mm	0.3228
			P	0.3230
			8.25 mm	0.3248
7/16-18	0.3745	0.3844	3/8 in.	0.3750
			V	0.3770
			9.6 mm	0.3780
			9.7 mm	0.3819
1/2-16	0.4292	0.4395	11 mm	0.4331
			7/16 in.	0.4375
9/16-16	0.4917	0.5020	12.5 mm	0.4921
			1/2 in.	0.5000
5/8-14	0.5442	0.5549	35/64 in.	0.5469
			14 mm	0.5512
11/16-14	0.6067	0.6174	39/64 in.	0.6094
			15.5 mm	0.6102
3/4-12	0.6555	0.6669	21/32 in.	0.6562
13/16-12	0.7180	0.7294	23/32 in.	0.7188
7/8-11	0.7720	0.7838	25/32 in.	0.7812
1-10	0.8868	0.8990	57/64 in.	0.8906
1 1/8-9	0.9992	1.0120	1.0 in.	1.0000
			25.5 mm	1.0039
1 1/4-9	1.1242	1.1370	1 1/8 in.	1.1250
1 3/8-8	1.2335	1.2470	1 15/64 in.	1.2344
			31.5 mm	1.2402
1 1/2-8	1.3585	1.3720	34.5 mm	1.3583
			1 23/64 in.	1.3594

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* This table is for reference only. It may be that, due to unfavorable manufacturing conditions, the use of a drill given in this list will not result in the production of minor diameters lying within the specified maximum and minimum limits.

TABLE 24a.—SUGGESTED TAP DRILL SIZES*
Screw Threads of Truncated Whitworth Form British Standard Pipe (Parallel)
(For general engineering purposes)

Nominal Thread Size	Minor Diam. of Nut, in Inches		Stock Drill	
	Min.	Max.	Designation	Decimal Size in Inches
$\frac{1}{8}$-28	0.3425	0.3483	8.7 mm	0.3425
			$\frac{11}{32}$ in.	0.3437
			8.75 mm	0.3445
			8.8 mm	0.3465
$\frac{1}{4}$-19	0.4584	0.4681	$\frac{29}{64}$ in.	0.4531†
$\frac{3}{8}$-19	0.5964	0.6061	$\frac{19}{32}$ in.	0.5937†
$\frac{1}{2}$-14	0.7442	0.7549	19 mm	0.7480
			$\frac{3}{4}$ in.	0.7500
$\frac{5}{8}$-14	0.8212	0.8319	21 mm	0.8268
			$\frac{53}{64}$ in.	0.8281
$\frac{3}{4}$-14	0.9602	0.9709	24.5 mm	0.9646
			$\frac{31}{32}$ in.	0.9687
$\frac{7}{8}$-14	1.1082	1.1189	$1\frac{7}{64}$ in.	1.1094
1-11	1.2060	1.2178	$1\frac{13}{64}$ in.	1.2031†
$1\frac{1}{4}$-11	1.5470	1.5588	$1\frac{35}{64}$ in.	1.5469†
			39.5 mm	1.5551
$1\frac{1}{2}$-11	1.7790	1.7908	$1\frac{25}{32}$ in.	1.7812

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* This table is for reference only. It may be that, due to unfavorable manufacturing conditions, the use of a drill given in this list will not result in the production of minor diameters lying within the specified maximum and minimum limits.

† These drills are not within the minor diameter tolerance but are the nearest smaller standard size. Provision should be made for machining to size.

TABLE 25.—BRITISH STANDARD WHITWORTH SCREW THREADS—BASIC SIZES

1	2	3	4	5	6	7	8
Nominal Diameter, in Inches	Number of Threads per Inch	Pitch, in Inches	Depth of Thread, in Inches	Major Diameter, in Inches	Effective Diameter, in Inches	Minor Diameter, in Inches	Cross-Sectional Area at Bottom of Thread, in Square Inches
1/8*	40	0.025 00	0.0160	0.1250	0.1090	0.0930	0.0068
3/16	24	0.041 67	0.0267	0.1875	0.1608	0.1341	0.0141
1/4	20	0.050 00	0.0320	0.2500	0.2180	0.1860	0.0272
5/16	18	0.055 56	0.0356	0.3125	0.2769	0.2413	0.0457
3/8	16	0.062 50	0.0400	0.3750	0.3350	0.2950	0.0683
7/16	14	0.071 43	0.0457	0.4375	0.3918	0.3461	0.0941
1/2	12	0.083 33	0.0534	0.5000	0.4466	0.3932	0.1214
9/16	12	0.083 33	0.0534	0.5625	0.5091	0.4557	0.1631
5/8	11	0.090 91	0.0582	0.6250	0.5668	0.5086	0.2032
11/16†	11	0.090 91	0.0582	0.6875	0.6293	0.5711	0.2562
3/4	10	0.100 00	0.0640	0.7500	0.6860	0.6220	0.3039
7/8	9	0.111 11	0.0711	0.8750	0.8039	0.7328	0.4218
1	8	0.125 00	0.0800	1.0000	0.9200	0.8400	0.5542
1 1/8	7	0.142 86	0.0915	0.1250	1.0335	0.9420	0.6969
1 1/4	7	0.142 86	0.0915	1.2500	1.1585	1.0670	0.8942
1 1/2	6	0.166 67	0.1067	1.5000	1.3933	1.2866	1.300
1 3/4	5	0.200 00	0.1281	1.7500	1.6219	1.4938	1.753
2	4.5	0.222 22	0.1423	2.0000	1.8577	1.7154	2.311
2 1/4	4	0.250 00	0.1601	2.2500	2.0899	1.9298	2.925
2 1/2	4	0.250 00	0.1601	2.5000	2.3399	2.1798	3.732
2 3/4	3.5	0.285 71	0.1830	2.7500	2.5670	2.3840	4.464
3	3.5	0.285 71	0.1830	3.0000	2.8170	2.6340	5.449
3 1/4	3.25	0.307 69	0.1970	3.2500	3.0530	2.8560	6.406
3 1/2	3.25	0.307 69	0.1970	3.5000	3.3030	3.1060	7.577
3 3/4	3	0.333 33	0.2134	3.7500	3.5366	3.3232	8.674
4	3	0.333 33	0.2134	4.0000	3.7866	3.5732	10.03
4 1/2	2.875	0.347 83	0.2227	4.5000	4.2773	4.0546	12.91
5	2.75	0.363 64	0.2328	5.0000	4.7672	4.5344	16.15
5 1/2	2.625	0.380 95	0.2439	5.5000	5.2561	5.0122	19.73
6	2.5	0.400 00	0.2561	6.0000	5.7439	5.4878	23.65

*** Dimensionally the 1/8 in. × 40 t.p.i. thread belongs more appropriately to the British Standard fine series, but it has for so long been associated with the Whitworth series that it is now included herein.**

† To be dispensed with wherever possible.

TABLE 26.—BRITISH STANDARD WHITWORTH LIMITS AND TOLERANCES, CLOSE FIT, BOLTS AND NUTS

1	2	3	4	5	6	7	8	9	10	11	3	4	5	6	7	8	9
Nominal Diameter, in Inches	No. of Threads per Inch	Bolts									Nuts						
		Major Diameter, in Inches			Effective Diameter, in Inches			Minor Diameter, in Inches			Major Diameter, in Inches	Effective Diameter, in Inches			Minor Diameter. in Inches		
		Max.	Tol.	Min.	Max.	Tol.	Min.	Max.	Tol.	Min.	Min.	Max.	Tol.	Min.	Max.	Tol.	Min.
$\frac{1}{8}$	40	0.1250	0.0035	0.1215	0.1090	0.0019	0.1071	0.0930	0.0040	0.0890	0.1250	0.1109	0.0019	0.1090	0.1020	0.0090	0.0930
$\frac{3}{16}$	24	0.1875	0.0043	0.1832	0.1608	0.0023	0.1585	0.1341	0.0050	0.1291	0.1875	0.1631	0.0023	0.1608	0.1474	0.0133	0.1341
$\frac{1}{4}$	20	0.2500	0.0048	0.2452	0.2180	0.0026	0.2154	0.1860	0.0055	0.1805	0.2500	0.2206	0.0026	0.2180	0.2030	0.0170	0.1860
$\frac{5}{16}$	18	0.3125	0.0052	0.3073	0.2769	0.0028	0.2741	0.2413	0.0059	0.2354	0.3125	0.2797	0.0028	0.2769	0.2594	0.0181	0.2413
$\frac{3}{8}$	16	0.3750	0.0055	0.3695	0.3350	0.0030	0.3320	0.2950	0.0062	0.2888	0.3750	0.3380	0.0030	0.3350	0.3145	0.0195	0.2950
$\frac{7}{16}$	14	0.4375	0.0059	0.4316	0.3918	0.0032	0.3886	0.3461	0.0067	0.3394	0.4375	0.3950	0.0032	0.3918	0.3674	0.0213	0.3461
$\frac{1}{2}$	12	0.5000	0.0063	0.4937	0.4466	0.0034	0.4432	0.3932	0.0072	0.3860	0.5000	0.4500	0.0034	0.4466	0.4169	0.0237	0.3932
$\frac{9}{16}$	12	0.5625	0.0065	0.5560	0.5091	0.0036	0.5055	0.4557	0.0074	0.4483	0.5625	0.5127	0.0036	0.5091	0.4794	0.0237	0.4557
$\frac{5}{8}$	11	0.6250	0.0067	0.6183	0.5668	0.0037	0.5631	0.5086	0.0076	0.5010	0.6250	0.5705	0.0037	0.5668	0.5338	0.0252	0.5086
$\frac{11}{16}$*	11	0.6875	0.0068	0.6807	0.6293	0.0038	0.6255	0.5711	0.0077	0.5634	0.6875	0.6331	0.0038	0.6293	0.5963	0.0252	0.5711
$\frac{3}{4}$	10	0.7500	0.0072	0.7428	0.6860	0.0040	0.6820	0.6220	0.0081	0.6139	0.7500	0.6900	0.0040	0.6860	0.6490	0.0270	0.6220
$\frac{7}{8}$	9	0.8750	0.0076	0.8674	0.8039	0.0043	0.7996	0.7328	0.0086	0.7242	0.8750	0.8082	0.0043	0.8039	0.7620	0.0292	0.7328
1	8	1.0000	0.0080	0.9920	0.9200	0.0045	0.9155	0.8400	0.0091	0.8309	1.0000	0.9245	0.0045	0.9200	0.8720	0.0320	0.8400
$1\frac{1}{8}$	7	1.1250	0.0086	1.1164	1.0335	0.0048	1.0287	0.9420	0.0097	0.9323	1.1250	1.0383	0.0048	1.0335	0.9776	0.0356	0.9420
$1\frac{1}{4}$	7	1.2500	0.0087	1.2413	1.1585	0.0049	1.1536	1.0670	0.0098	1.0572	1.2500	1.1634	0.0049	1.1585	1.1026	0.0356	1.0670
$1\frac{1}{2}$	6	1.5000	0.0094	1.4906	1.3933	0.0053	1.3880	1.2866	0.0106	1.2760	1.5000	1.3986	0.0053	1.3933	1.3269	0.0403	1.2866
$1\frac{3}{4}$	5	1.7500	0.0102	1.7398	1.6219	0.0057	1.6162	1.4938	0.0115	1.4823	1.7500	1.6276	0.0057	1.6219	1.5408	0.0470	1.4938
2	4.5	2.0000	0.0108	1.9892	1.8577	0.0061	1.8516	1.7154	0.0122	1.7032	2.0000	1.8638	0.0061	1.8577	1.7668	0.0514	1.7154
$2\frac{1}{4}$	4	2.2500	0.0114	2.2386	2.0899	0.0064	2.0835	1.9298	0.0129	1.9169	2.2500	2.0963	0.0064	2.0899	1.9868	0.0570	1.9298
$2\frac{1}{2}$	4	2.5000	0.0116	2.4884	2.3399	0.0066	2.3333	2.1798	0.0131	2.1667	2.5000	2.3465	0.0066	2.3399	2.2368	0.0570	2.1798
$2\frac{3}{4}$	3.5	2.7500	0.0123	2.7377	2.5670	0.0070	2.5600	2.3840	0.0139	2.3701	2.7500	2.5740	0.0070	2.5670	2.4481	0.0641	2.3840
3	3.5	3.0000	0.0125	2.9875	2.8170	0.0072	2.8098	2.6340	0.0141	2.6199	3.0000	2.8242	0.0072	2.8170	2.6981	0.0641	2.6340

* To be dispensed with wherever possible.

TABLE 27.—BRITISH STANDARD WHITWORTH LIMITS AND TOLERANCES, MEDIUM FIT, BOLTS AND NUTS

1	2	3	4	5	6	7	8	9	10	11	3	4	5	6	7	8	9
		Bolts									Nuts						
Nominal Diameter, in Inches	No. of Threads per Inch	Major Diameter, in Inches			Effective Diameter, in Inches			Minor Diameter, in Inches			Major Diameter, in Inches	Effective Diameter, in Inches			Minor Diameter, in Inches		
		Max.	Tol.	Min.	Max.	Tol.	Min.	Max.	Tol.	Min.	Min.	Max.	Tol.	Min.	Max.	Tol.	Min.
1/8	40	0.1250	0.0045	0.1205	0.1090	0.0029	0.1061	0.0930	0.0061	0.0869	0.1250	0.1119	0.0029	0.1090	0.1020	0.0090	0.0930
3/16	24	0.1875	0.0055	0.1820	0.1608	0.0035	0.1573	0.1341	0.0076	0.1265	0.1875	0.1643	0.0035	0.1608	0.1474	0.0133	0.1341
1/4	20	0.2500	0.0061	0.2439	0.2180	0.0039	0.2141	0.1860	0.0084	0.1776	0.2500	0.2219	0.0039	0.2180	0.2030	0.0170	0.1860
5/16	18	0.3125	0.0066	0.3059	0.2769	0.0042	0.2727	0.2413	0.0089	0.2324	0.3125	0.2811	0.0042	0.2769	0.2594	0.0181	0.2413
3/8	16	0.3750	0.0070	0.3680	0.3350	0.0045	0.3305	0.2950	0.0095	0.2855	0.3750	0.3395	0.0045	0.3350	0.3145	0.0195	0.2950
7/16	14	0.4375	0.0075	0.4300	0.3918	0.0048	0.3870	0.3461	0.0101	0.3360	0.4375	0.3966	0.0048	0.3918	0.3674	0.0213	0.3461
1/2	12	0.5000	0.0081	0.4919	0.4466	0.0052	0.4414	0.3932	0.0110	0.3822	0.5000	0.4518	0.0052	0.4466	0.4169	0.0237	0.3932
9/16	12	0.5625	0.0082	0.5543	0.5091	0.0053	0.5038	0.4557	0.0111	0.4446	0.5625	0.5144	0.0053	0.5091	0.4794	0.0237	0.4557
5/8	11	0.6250	0.0086	0.6164	0.5668	0.0056	0.5612	0.5086	0.0116	0.4970	0.6250	0.5724	0.0056	0.5668	0.5338	0.0252	0.5086
11/16*	11	0.6875	0.0088	0.6787	0.6293	0.0058	0.6235	0.5711	0.0118	0.5593	0.6875	0.6351	0.0058	0.6293	0.5963	0.0252	0.5711
3/4	10	0.7500	0.0092	0.7408	0.6860	0.0060	0.6800	0.6220	0.0123	0.6097	0.7500	0.6920	0.0060	0.6860	0.6490	0.0270	0.6220
7/8	9	0.8750	0.0097	0.8653	0.8039	0.0064	0.7975	0.7328	0.0131	0.7197	0.8750	0.8103	0.0064	0.8039	0.7620	0.0292	0.7328
1	8	1.0000	0.0103	0.9897	0.9200	0.0068	0.9132	0.8400	0.0139	0.8261	1.0000	0.9268	0.0068	0.9200	0.8720	0.0320	0.8400
1 1/8	7	1.1250	0.0110	1.1140	1.0335	0.0072	1.0263	0.9420	0.0148	0.9272	1.1250	1.0407	0.0072	1.0335	0.9776	0.0356	0.9420
1 1/4	7	1.2500	0.0112	1.2388	1.1585	0.0074	1.1511	1.0670	0.0150	1.0520	1.2500	1.1659	0.0074	1.1585	1.1026	0.0356	1.0670
1 1/2	6	1.5000	0.0121	1.4879	1.3933	0.0080	1.3853	1.2866	0.0162	1.2704	1.5000	1.4013	0.0080	1.3933	1.3269	0.0403	1.2866
1 3/4	5	1.7500	0.0131	1.7369	1.6219	0.0086	1.6133	1.4938	0.0175	1.4763	1.7500	1.6305	0.0086	1.6219	1.5408	0.0470	1.4938
2	4.5	2.0000	0.0138	1.9862	1.8577	0.0091	1.8486	1.7154	0.0185	1.6969	2.0000	1.8668	0.0091	1.8577	1.7668	0.0514	1.7154
2 1/4	4	2.2500	0.0146	2.2354	2.0899	0.0096	2.0803	1.9298	0.0196	1.9102	2.2500	2.0995	0.0096	2.0899	1.9868	0.0570	1.9298
2 1/2	4	2.5000	0.0150	2.4850	2.3399	0.0100	2.3299	2.1798	0.0200	2.1598	2.5000	2.3499	0.0100	2.3399	2.2368	0.0570	2.1798
2 3/4	3.5	2.7500	0.0157	2.7343	2.5670	0.0104	2.5566	2.3840	0.0211	2.3629	2.7500	2.5774	0.0104	2.5670	2.4481	0.0641	2.3840
3	3.5	3.0000	0.0161	2.9839	2.8170	0.0108	2.8062	2.6340	0.0215	2.6125	3.0000	2.8278	0.0108	2.8170	2.6981	0.0641	2.6340

* To be dispensed with wherever possible.

TABLE 28.—BRITISH STANDARD WHITWORTH LIMITS AND TOLERANCES, FREE FIT, BOLTS AND NUTS

1	2	3	4	5	6	7	8	9	10	11	3	4	5	6	7	8	9
		Bolts									Nuts						
Nominal Diameter, in Inches	No. of Threads per Inch	Major Diameter, in Inches			Effective Diameter, in Inches			Minor Diameter, in Inches			Major Diameter, in Inches	Effective Diameter, in Inches			Minor Diameter, in Inches		
		Max.	Tol.	Min.	Max.	Tol.	Min.	Max.	Tol.	Min.	Min.	Max.	Tol.	Min.	Max.	Tol.	Min.
1/8	40	0.1250	0.0059	0.1191	0.1090	0.0043	0.1047	0.0930	0.0075	0.0855	0.1250	0.1133	0.0043	0.1090	0.1020	0.0090	0.0930
3/16	24	0.1875	0.0072	0.1803	0.1608	0.0052	0.1556	0.1341	0.0093	0.1248	0.1875	0.1660	0.0052	0.1608	0.1474	0.0133	0.1341
1/4	20	0.2500	0.0080	0.2420	0.2180	0.0058	0.2122	0.1860	0.0103	0.1757	0.2500	0.2238	0.0058	0.2180	0.2030	0.0170	0.1860
5/16	18	0.3125	0.0087	0.3038	0.2769	0.0063	0.2706	0.2413	0.0110	0.2303	0.3125	0.2832	0.0063	0.2769	0.2594	0.0181	0.2413
3/8	16	0.3750	0.0093	0.3657	0.3350	0.0068	0.3282	0.2950	0.0118	0.2832	0.3750	0.3418	0.0068	0.3350	0.3145	0.0195	0.2950
7/16	14	0.4375	0.0100	0.4275	0.3918	0.0073	0.3845	0.3461	0.0126	0.3335	0.4375	0.3991	0.0073	0.3918	0.3674	0.0213	0.3461
1/2	12	0.5000	0.0106	0.4894	0.4466	0.0077	0.4389	0.3932	0.0135	0.3797	0.5000	0.4543	0.0077	0.4466	0.4169	0.0237	0.3932
9/16	12	0.5625	0.0109	0.5516	0.5091	0.0080	0.5011	0.4557	0.0138	0.4419	0.5625	0.5171	0.0080	0.5091	0.4794	0.0237	0.4557
5/8	11	0.6250	0.0114	0.6136	0.5668	0.0084	0.5584	0.5086	0.0144	0.4942	0.6250	0.5752	0.0084	0.5668	0.5338	0.0252	0.5086
11/16*	11	0.6875	0.0116	0.6759	0.6293	0.0086	0.6207	0.5711	0.0146	0.5565	0.6875	0.6379	0.0086	0.6293	0.5963	0.0252	0.5711
3/4	10	0.7500	0.0122	0.7378	0.6860	0.0090	0.6770	0.6220	0.0153	0.6067	0.7500	0.6950	0.0090	0.6860	0.6490	0.0270	0.6220
7/8	9	0.8750	0.0129	0.8621	0.8039	0.0096	0.7943	0.7328	0.0163	0.7165	0.8750	0.8135	0.0096	0.8039	0.7620	0.0292	0.7328
1	8	1.0000	0.0137	0.9863	0.9200	0.0102	0.9098	0.8400	0.0173	0.8227	1.0000	0.9302	0.0102	0.9200	0.8720	0.0320	0.8400
1 1/8	7	1.1250	0.0145	1.1105	1.0335	0.0107	1.0228	0.9420	0.0183	0.9237	1.1250	1.0442	0.0107	1.0335	0.9776	0.0356	0.9420
1 1/4	7	1.2500	0.0149	1.2351	1.1585	0.0111	1.1474	1.0670	0.0187	1.0483	1.2500	1.1696	0.0111	1.1585	1.1026	0.0356	1.0670
1 1/2	6	1.5000	0.0161	1.4839	1.3933	0.0120	1.3813	1.2866	0.0202	1.2664	1.5000	1.4053	0.0120	1.3933	1.3269	0.0403	1.2866
1 3/4	5	1.7500	0.0174	1.7326	1.6219	0.0129	1.6090	1.4938	0.0218	1.4720	1.7500	1.6348	0.0129	1.6219	1.5408	0.0470	1.4938
2	4.5	2.0000	0.0184	1.9816	1.8577	0.0137	1.8440	1.7154	0.0231	1.6923	2.0000	1.8714	0.0137	1.8577	1.7668	0.0514	1.7154
2 1/4	4	2.2500	0.0194	2.2306	2.0899	0.0144	2.0755	1.9298	0.0244	1.9054	2.2500	2.1043	0.0144	2.0899	1.9868	0.0570	1.9298
2 1/2	4	2.5000	0.0199	2.4801	2.3399	0.0149	2.3250	2.1798	0.0249	2.1549	2.5000	2.3548	0.0149	2.3399	2.2368	0.0570	2.1798
2 3/4	3.5	2.7500	0.0210	2.7290	2.5670	0.0157	2.5513	2.3840	0.0264	2.3576	2.7500	2.5827	0.0157	2.5670	2.4481	0.0641	2.3840
3	3.5	3.0000	0.0214	2.9786	2.8170	0.0161	2.8009	2.6340	0.0268	2.6072	3.0000	2.8331	0.0161	2.8170	2.6981	0.0641	2.6340

* To be dispensed with wherever possible.

TABLE 28*a*.—BRITISH STANDARD FINE SCREW THREADS—BASIC SIZES

1	2	3	4	5	6	7	8
Nominal Diameter, in Inches	Number of Threads per Inch	Pitch, in Inches	Depth of Thread, in Inches	Major Diameter, in Inches	Effective Diameter, in Inches	Minor Diameter, in Inches	Cross Sectional Area at Bottom of Thread, in Square Inches
$\frac{3}{16}$	32	0.031 25	0.0200	0.1875	0.1675	0.1475	0.0171
$\frac{7}{32}$	28	0.035 71	0.0229	0.2188	0.1959	0.1730	0.0235
$\frac{1}{4}$	26	0.038 46	0.0246	0.2500	0.2254	0.2008	0.0317
$\frac{9}{32}$	26	0.038 46	0.0246	0.2812	0.2566	0.2320	0.0423
$\frac{5}{16}$	22	0.045 45	0.0291	0.3125	0.2834	0.2543	0.0508
$\frac{3}{8}$	20	0.050 00	0.0320	0.3750	0.3430	0.3110	0.0760
$\frac{7}{16}$	18	0.055 56	0.0356	0.4375	0.4019	0.3663	0.1054
$\frac{1}{2}$	16	0.062 50	0.0400	0.5000	0.4600	0.4200	0.1385
$\frac{9}{16}$	16	0.062 50	0.0400	0.5625	0.5225	0.4825	0.1828
$\frac{5}{8}$	14	0.071 43	0.0457	0.6250	0.5793	0.5336	0.2236
$\frac{11}{16}$	14	0.071 43	0.0457	0.6875	0.6418	0.5961	0.2791
$\frac{3}{4}$	12	0.083 33	0.0534	0.7500	0.6966	0.6432	0.3249
$\frac{13}{16}$	12	0.083 33	0.0534	0.8125	0.7591	0.7057	0.3911
$\frac{7}{8}$	11	0.090 91	0.0582	0.8750	0.8168	0.7586	0.4520
1	10	0.100 00	0.0640	1.0000	0.9360	0.8720	0.5972
$1\frac{1}{8}$	9	0.111 11	0.0711	1.1250	1.0539	0.9828	0.7586
$1\frac{1}{4}$	9	0.111 11	0.0711	1.2500	1.1789	1.1078	0.9639
$1\frac{3}{8}$	8	0.125 00	0.0800	1.3750	1.2950	1.2150	1.159
$1\frac{1}{2}$	8	0.125 00	0.0800	1.5000	1.4200	1.3400	1.410
$1\frac{5}{8}$	8	0.125 00	0.0800	1.6250	1.5450	1.4650	1.686
$1\frac{3}{4}$	7	0.142 86	0.0915	1.7500	1.6585	1.5670	1.928
2	7	0.142 86	0.0915	2.0000	1.9085	1.8170	2.593
$2\frac{1}{4}$	6	0.166 67	0.1067	2.2500	2.1433	2.0366	3.258
$2\frac{1}{2}$	6	0.166 67	0.1067	2.5000	2.3933	2.2866	4.106
$2\frac{3}{4}$	6	0.166 67	0.1067	2.7500	2.6433	2.5366	5.054
3	5	0.200 00	0.1281	3.0000	2.8719	2.7438	5.913
$3\frac{1}{4}$	5	0.200 00	0.1281	3.2500	3.1219	2.9938	7.039
$3\frac{1}{2}$	4.5	0.222 22	0.1423	3.5000	3.3577	3.2154	8.120
$3\frac{3}{4}$	4.5	0.222 22	0.1423	3.7500	3.6077	3.4654	9.432
4	4.5	0.222 22	0.1423	4.0000	3.8577	3.7154	10.84
$4\frac{1}{4}$	4	0.250 00	0.1601	4.2500	4.0899	3.9298	12.13

NOTE.—It is recommended that for larger diameters in this series four threads per inch be used.

TABLE 28b.—BRITISH STANDARD FINE LIMITS AND TOLERANCES, CLOSE FIT, BOLTS AND NUTS

1	2	3	4	5	6	7	8	9	10	11	3	4	5	6	7	8	9
		Bolts									Nuts						
Nominal Diameter, in Inches	No. of Threads per Inch	Major Diameter, in Inches			Effective Diameter, in Inches			Minor Diameter, in Inches			Major Diameter, in Inches	Effective Diameter, in Inches			Minor Diameter, in Inches		
		Max.	Tol.	Min.	Max.	Tol.	Min.	Max.	Tol.	Min.	Min.	Max.	Tol.	Min.	Max.	Tol.	Min.
3/16	32	0.1875	0.0040	0.1835	0.1675	0.0022	0.1653	0.1475	0.0045	0.1430	0.1875	0.1697	0.0022	0.1675	0.1577	0.0102	0.1475
7/32	28	0.2188	0.0043	0.2145	0.1959	0.0024	0.1935	0.1730	0.0049	0.1681	0.2188	0.1983	0.0024	0.1959	0.1841	0.0111	0.1730
1/4	26	0.2500	0.0045	0.2455	0.2254	0.0025	0.2229	0.2008	0.0050	0.1958	0.2500	0.2279	0.0025	0.2254	0.2125	0.0117	0.2008
9/32	26	0.2812	0.0046	0.2766	0.2566	0.0026	0.2540	0.2320	0.0051	0.2269	0.2812	0.2592	0.0026	0.2566	0.2437	0.0117	0.2320
5/16	22	0.3125	0.0048	0.3077	0.2834	0.0027	0.2807	0.2543	0.0055	0.2488	0.3125	0.2861	0.0027	0.2834	0.2684	0.0141	0.2543
3/8	20	0.3750	0.0051	0.3699	0.3430	0.0029	0.3401	0.3110	0.0058	0.3052	0.3750	0.3459	0.0029	0.3430	0.3280	0.0170	0.3110
7/16	18	0.4375	0.0055	0.4320	0.4019	0.0031	0.3988	0.3663	0.0062	0.3601	0.4375	0.4050	0.0031	0.4019	0.3844	0.0181	0.3663
1/2	16	0.5000	0.0058	0.4942	0.4600	0.0033	0.4567	0.4200	0.0065	0.4135	0.5000	0.4633	0.0033	0.4600	0.4395	0.0195	0.4200
9/16	16	0.5625	0.0059	0.5566	0.5225	0.0034	0.5191	0.4825	0.0066	0.4759	0.5625	0.5259	0.0034	0.5225	0.5020	0.0195	0.4825
5/8	14	0.6250	0.0063	0.6187	0.5793	0.0036	0.5757	0.5336	0.0071	0.5265	0.6250	0.5829	0.0036	0.5793	0.5549	0.0213	0.5336
11/16	14	0.6875	0.0064	0.6811	0.6418	0.0037	0.6381	0.5961	0.0072	0.5889	0.6875	0.6455	0.0037	0.6418	0.6174	0.0213	0.5961
3/4	12	0.7500	0.0068	0.7432	0.6966	0.0039	0.6927	0.6432	0.0077	0.6355	0.7500	0.7005	0.0039	0.6966	0.6669	0.0237	0.6432
13/16	12	0.8125	0.0069	0.8056	0.7591	0.0040	0.7551	0.7057	0.0078	0.6979	0.8125	0.7631	0.0040	0.7591	0.7294	0.0237	0.7057
7/8	11	0.8750	0.0072	0.8678	0.8168	0.0042	0.8126	0.7586	0.0081	0.7505	0.8750	0.8210	0.0042	0.8168	0.7838	0.0252	0.7586
1	10	1.0000	0.0076	0.9924	0.9360	0.0044	0.9316	0.8720	0.0085	0.8635	1.0000	0.9404	0.0044	0.9360	0.8990	0.0270	0.8720
1 1/8	9	1.1250	0.0079	1.1171	1.0539	0.0046	1.0493	0.9828	0.0089	0.9739	1.1250	1.0585	0.0046	1.0539	1.0120	0.0292	0.9828
1 1/4	9	1.2500	0.0081	1.2419	1.1789	0.0048	1.1741	1.1078	0.0091	1.0987	1.2500	1.1837	0.0048	1.1789	1.1370	0.0292	1.1078
1 3/8	8	1.3750	0.0085	1.3665	1.2950	0.0050	1.2900	1.2150	0.0096	1.2054	1.3750	1.3000	0.0050	1.2950	1.2470	0.0320	1.2150
1 1/2	8	1.5000	0.0087	1.4913	1.4200	0.0052	1.4148	1.3400	0.0098	1.3302	1.5000	1.4252	0.0052	1.4200	1.3720	0.0320	1.3400

TABLE 28c.—BRITISH STANDARD FINE LIMITS AND TOLERANCES, MEDIUM FIT, BOLTS AND NUTS

1	2	3	4	5	6	7	8	9	10	11	3	4	5	6	7	8	9
		Bolts									Nuts						
Nominal Diameter, in Inches	No. of Threads per Inch	Major Diameter, in Inches			Effective Diameter, in Inches			Minor Diameter, in Inches			Major Diameter, in Inches	Effective Diameter, in Inches			Minor Diameter, in Inches		
		Max.	Tol.	Min.	Max.	Tol.	Min.	Max.	Tol.	Min.	Min.	Max.	Tol.	Min.	Max.	Tol.	Min.
3/16	32	0.1875	0.0051	0.1824	0.1675	0.0033	0.1642	0.1475	0.0068	0.1407	0.1875	0.1708	0.0033	0.1675	0.1577	0.0102	0.1475
7/32	28	0.2188	0.0055	0.2133	0.1959	0.0036	0.1923	0.1730	0.0074	0.1656	0.2188	0.1995	0.0036	0.1959	0.1841	0.0111	0.1730
1/4	26	0.2500	0.0057	0.2443	0.2254	0.0037	0.2217	0.2008	0.0076	0.1932	0.2500	0.2291	0.0037	0.2254	0.2125	0.0117	0.2008
9/32	26	0.2812	0.0059	0.2753	0.2566	0.0039	0.2527	0.2320	0.0078	0.2242	0.2812	0.2605	0.0039	0.2566	0.2437	0.0117	0.2320
5/16	22	0.3125	0.0062	0.3063	0.2834	0.0041	0.2793	0.2543	0.0084	0.2459	0.3125	0.2875	0.0041	0.2834	0.2684	0.0141	0.2543
3/8	20	0.3750	0.0066	0.3684	0.3430	0.0044	0.3386	0.3110	0.0089	0.3021	0.3750	0.3474	0.0044	0.3430	0.3280	0.0170	0.3110
7/16	18	0.4375	0.0071	0.4304	0.4019	0.0047	0.3972	0.3663	0.0094	0.3569	0.4375	0.4066	0.0047	0.4019	0.3844	0.0181	0.3663
1/2	16	0.5000	0.0075	0.4925	0.4600	0.0050	0.4550	0.4200	0.0100	0.4100	0.5000	0.4650	0.0050	0.4600	0.4395	0.0195	0.4200
9/16	16	0.5625	0.0077	0.5548	0.5225	0.0052	0.5173	0.4825	0.0102	0.4723	0.5625	0.5277	0.0052	0.5225	0.5020	0.0195	0.4825
5/8	14	0.6250	0.0081	0.6169	0.5793	0.0054	0.5739	0.5336	0.0107	0.5229	0.6250	0.5847	0.0054	0.5793	0.5549	0.0213	0.5336
11/16	14	0.6875	0.0083	0.6792	0.6418	0.0056	0.6362	0.5961	0.0109	0.5852	0.6875	0.6474	0.0056	0.6418	0.6174	0.0213	0.5961
3/4	12	0.7500	0.0088	0.7412	0.6966	0.0059	0.6907	0.6432	0.0117	0.6315	0.7500	0.7025	0.0059	0.6966	0.6669	0.0237	0.6432
13/16	12	0.8125	0.0089	0.8036	0.7591	0.0060	0.7531	0.7057	0.0118	0.6939	0.8125	0.7651	0.0060	0.7591	0.7294	0.0237	0.7057
7/8	11	0.8750	0.0092	0.8658	0.8168	0.0062	0.8106	0.7586	0.0122	0.7464	0.8750	0.8230	0.0062	0.8168	0.7838	0.0252	0.7586
1	10	1.0000	0.0098	0.9902	0.9360	0.0066	0.9294	0.8720	0.0129	0.8591	1.0000	0.9426	0.0066	0.9360	0.8990	0.0270	0.8720
1 1/8	9	1.1250	0.0102	1.1148	1.0539	0.0069	1.0470	0.9828	0.0136	0.9692	1.1250	1.0608	0.0069	1.0539	1.0120	0.0292	0.9828
1 1/4	9	1.2300	0.0105	1.2395	1.1789	0.0072	1.1717	1.1078	0.0139	1.0939	1.2500	1.1861	0.0072	1.1789	1.1370	0.0292	1.1078
1 3/8	8	1.3750	0.0110	1.3640	1.2950	0.0075	1.2885	1.2150	0.0146	1.2004	1.3750	1.3025	0.0075	1.2950	1.2470	0.0320	1.2150
1 1/2	8	1.5000	0.0112	1.4888	1.4200	0.0077	1.4123	1.3400	0.0148	1.3252	1.5000	1.4277	0.0077	1.4200	1.3720	0.0320	1.3400

TABLE 28*d*.—BRITISH STANDARD FINE LIMITS AND TOLERANCES, FREE FIT, BOLTS AND NUTS

1	2	3	4	5	6	7	8	9	10	11	3	4	5	6	7	8	9
		Bolts									Nuts						
Nominal Diameter, in Inches	No. of Threads per Inch	Major Diameter, in Inches			Effective Diameter, in Inches			Minor Diameter, in Inches			Major Diameter, in Inches	Effective Diameter, in Inches			Minor Diameter, in Inches		
		Max.	Tol.	Min.	Max.	Tol.	Min.	Max.	Tol.	Min.	Min.	Max.	Tol.	Min.	Max.	Tol.	Min.
3/16	32	0.1875	0.0068	0.1807	0.1675	0.0050	0.1625	0.1475	0.0085	0.1390	0.1875	0.1725	0.0050	0.1675	0.1577	0.0102	0.1475
7/32	28	0.2188	0.0072	0.2116	0.1959	0.0053	0.1906	0.1730	0.0091	0.1639	0.2188	0.2012	0.0053	0.1959	0.1841	0.0111	0.1730
1/4	26	0.2500	0.0076	0.2424	0.2254	0.0056	0.2198	0.2008	0.0095	0.1913	0.2500	0.2310	0.0056	0.2254	0.2125	0.0117	0.2008
9/32	26	0.2812	0.0078	0.2734	0.2566	0.0058	0.2508	0.2320	0.0097	0.2223	0.2812	0.2624	0.0058	0.2566	0.2437	0.0117	0.2320
5/16	22	0.3125	0.0083	0.3042	0.2834	0.0062	0.2772	0.2543	0.0105	0.2438	0.3125	0.2896	0.0062	0.2834	0.2684	0.0141	0.2543
3/8	20	0.3750	0.0088	0.3662	0.3430	0.0066	0.3364	0.3110	0.0111	0.2999	0.3750	0.3496	0.0066	0.3430	0.3280	0.0170	0.3110
7/16	18	0.4375	0.0094	0.4281	0.4019	0.0070	0.3949	0.3663	0.0117	0.3546	0.4375	0.4089	0.0070	0.4019	0.3844	0.0181	0.3663
1/2	16	0.5000	0.0099	0.4901	0.4600	0.0074	0.4526	0.4200	0.0124	0.4076	0.5000	0.4674	0.0074	0.4600	0.4395	0.0195	0.4200
9/16	16	0.5625	0.0102	0.5523	0.5225	0.0077	0.5148	0.4825	0.0127	0.4698	0.5625	0.5302	0.0077	0.5225	0.5020	0.0195	0.4825
5/8	14	0.6250	0.0108	0.6142	0.5793	0.0081	0.5712	0.5336	0.0134	0.5202	0.6250	0.5874	0.0081	0.5793	0.5549	0.0213	0.5336
11/16	14	0.6875	0.0111	0.6764	0.6418	0.0084	0.6334	0.5961	0.0137	0.5824	0.6875	0.6502	0.0084	0.6418	0.6174	0.0213	0.5961
3/4	12	0.7500	0.0117	0.7383	0.6966	0.0088	0.6878	0.6432	0.0146	0.6286	0.7500	0.7054	0.0088	0.6966	0.6669	0.0237	0.6432
13/16	12	0.8125	0.0119	0.8006	0.7591	0.0090	0.7501	0.7057	0.0148	0.6909	0.8125	0.7681	0.0090	0.7591	0.7294	0.0237	0.7057
7/8	11	0.8750	0.0123	0.8627	0.8168	0.0093	0.8075	0.7586	0.0153	0.7433	0.8750	0.8261	0.0093	0.8168	0.7838	0.0252	0.7586
1	10	1.0000	0.0131	0.9869	0.9360	0.0099	0.9261	0.8720	0.0162	0.8558	1.0000	0.9459	0.0099	0.9360	0.8990	0.0270	0.8720
1 1/8	9	1.1250	0.0137	1.1113	1.0539	0.0104	1.0435	0.9828	0.0171	0.9657	1.1250	1.0643	0.0104	1.0539	1.0120	0.0292	0.9828
1 1/4	9	1.2500	0.0141	1.2359	1.1789	0.0108	1.1681	1.1078	0.0175	1.0903	1.2500	1.1897	0.0108	1.1789	1.1370	0.0292	1.1078
1 3/8	8	1.3750	0.0148	1.3602	1.2950	0.0113	1.2837	1.2150	0.0184	1.1966	1.3750	1.3063	0.0113	1.2950	1.2470	0.0320	1.2150
1 1/2	8	1.5000	0.0151	1.4849	1.4200	0.0116	1.4084	1.3400	0.0187	1.3213	1.5000	1.4316	0.0116	1.4200	1.3720	0.0320	1.3400

TABLE 28*e*.—BRITISH STANDARD PIPE THREADS (PARALLEL)—BASIC SIZES

1	2	3	4	5	6	7	8
British Standard Pipe Size, in Inches	Number of Threads per Inch	Pitch, in Inches	Depth of Thread, in Inches	Major Diameter, in Inches	Effective Diameter, in Inches	Minor Diameter, in Inches	Cross Sectional Area at Bottom of Thread, in Square Inches
⅛	28	0.035 71	0.0229	0.3830	0.3601	0.3372	0.0893
¼	19	0.052 63	0.0337	0.5180	0.4843	0.4506	0.1595
⅜	19	0.052 63	0.0337	0.6560	0.6223	0.5886	0.2721
½	14	0.071 43	0.0457	0.8250	0.7793	0.7336	0.4227
⅝	14	0.071 43	0.0457	0.9020	0.8563	0.8106	0.5161
¾	14	0.071 43	0.0457	1.0410	0.9953	0.9496	0.7082
⅞	14	0.071 43	0.0457	1.1890	1.1433	1.0976	0.9462
1	11	0.090 91	0.0582	1.3090	1.2508	1.1926	1.117
1¼	11	0.090 91	0.0582	1.6500	1.5918	1.5336	1.847
1½	11	0.090 91	0.0582	1.8820	1.8238	1.7656	2.448
1¾	11	0.090 91	0.0582	2.1160	2.0578	1.9996	3.140
2	11	0.090 91	0.0582	2.3470	2.2888	2.2306	3.908
2¼	11	0.090 91	0.0582	2.5870	2.5288	2.4706	4.794
2½	11	0.090 91	0.0582	2.9600	2.9018	2.8436	6.351
2¾	11	0.090 91	0.0582	3.2100	3.1518	3.0936	7.517
3	11	0.090 91	0.0582	3.4600	3.4018	3.3436	8.780

TABLE 28f.—WHITWORTH SCREW THREADS OF SPECIAL DIAMETERS, PITCHES, AND LENGTHS OF ENGAGEMENT—SERIES OF PITCHES

1	2	3	4
No. of Threads per Inch	Pitch, in Inches	Standard Depth of Thread, in Inches	Double Standard Depth of Thread, in Inches
40	0.025 00	0.0160	0.0320
36	0.027 78	0.0178	0.0356
32	0.031 25	0.0200	0.0400
28	0.035 71	0.0229	0.0458
26	0.038 46	0.0246	0.0492
24	0.041 67	0.0267	0.0534
20	0.050 00	0.0320	0.0640
18	0.055 56	0.0356	0.0712
16	0.062 50	0.0400	0.0800
14	0.071 43	0.0457	0.0914
12	0.083 33	0.0534	0.1068
10	0.100 00	0.0640	0.1280
8	0.125 00	0.0800	0.1600
6	0.166 67	0.1067	0.2134
4	0.250 00	0.1601	0.3202

NOTE.—Basic effective diameter = basic major diameter − standard depth of thread (Col. 3).

Basic minor diameter = basic major diameter − twice standard depth of thread (Col. 4).

Table 28g.—Whitworth Screw Threads of Special Diameters, Pitches, and Lengths of Engagement

Tolerances for Major Diameter of Bolts, Minor Diameter of Bolts, and Minor Diameter of Nuts

(Unit of Tolerance = 0.001 In.)

1	2	3	4	5
	Bolts			Nuts
No. of Threads per Inch	Tolerance on Major Diameter—Addition to Be Made to Effective Diameter Tolerance All Fits	Tolerance on Minor Diameter—Addition to Be Made to Effective Diameter Tolerance		Tolerance on Minor Diameter
		Close Fit	Medium and Free Fits	All Fits
40	1.6	2.1	3.2	9.0
36	1.7	2.2	3.3	9.6
32	1.8	2.3	3.5	10.2
28	1.9	2.5	3.8	11.1
26	2.0	2.5	3.9	11.7
24	2.0	2.7	4.1	13.3
20	2.2	2.9	4.5	17.0
18	2.4	3.1	4.7	18.1
16	2.5	3.2	5.0	19.5
14	2.7	3.5	5.3	21.3
12	2.9	3.8	5.8	23.7
10	3.2	4.1	6.3	27.0
8	3.5	4.6	7.1	32.0
6	4.1	5.3	8.2	40.3
4	5.0	6.5	10.0	57.0

Table 28h.—Bolt Threads with Flat Crests (Truncated Threads)

No. of Threads per Inch	Maximum Permissible Deviation of Flat-crest Diameter below Basic Major Diameter of Thread, in Inches Close and Medium Fits	No. of Threads per Inch	Maximum Permissible Deviation of Flat-crest Diameter below Basic Major Diameter of Thread, in Inches Close and Medium Fits	No. of Threads per Inch	Maximum Permissible Deviation of Flat-crest Diameter below Basic Major Diameter of Thread, in Inches Close and Medium Fits
28	0.008	18	0.011	10	0.019
26	0.009	16	0.013	9	0.021
24	0.009	14	0.014	8	0.023
22	0.010	12	0.016	7	0.025
20	0.010	11	0.018	6	0.029

BRITISH ASSOCIATION SCREW THREADS (B.A.)

British Association threads differ in every way from the British Standard or Whitworth thread, except that they are rounded at top and bottom. The angle is 47½ degrees, and metric measurements are used, the standard sizes in millimeters being rounded off in each case to the second significant figure after calculation from the formulas below:

Pitch in millimeters = $(0.9)^n$ when n is number designating the screw.

Diameters = 6 × pitch.

Roots and crests are rounded with equal radii such that the double depth of thread = $\frac{6}{5}$ pitch.

These are for screws smaller than ¼ inch, similar to the American numbered series. The numbers, however, are opposite, No. 0 being the largest (see Table 29).

ROLLED THREADS

The rolled-thread process dates back more than 50 years and was first patented in England. It was first used on comparatively rough work, such as track bolts, but has come to be used on such fine work as the sizing of taps and screws for micrometers.

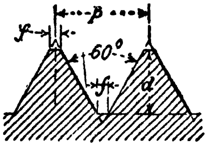
The thread is forced up into the dies so that the finished screw is larger than the original wire by about the depth of one thread. In this way the size of the wire to use for any screw may be found by subtracting the depth of one thread from the outside diameter of the screw. Exact allowance depends on material being rolled and other conditions.

The dies are usually flat plates of steel, having grooves of the same pitch and shape as the thread to be rolled. The dies can be easily laid out as follows:

Draw a horizontal line equal in length to the circumference of the *wire* or *blank*, and at its end draw a vertical line equal to the lead of the screw. The diagonal line made by joining these two points shows the angle of incline of the grooves. This can be done more easily if both the circumference and the pitch are laid out to *ten times* their actual dimensions.

The diameters of the blanks are the *pitch diameter* of the finished thread and can be found in the thread tables.

The leading thread forms now in use are:



American (National) Standard

p = pitch.
d = depth = $p \times 0.6495$.
f = flat = $\frac{p}{8}$.

This thread was devised by William Sellers, and recommended by the Franklin Institute. Later called U. S. Standard and now American Standard.

TABLE 29.—BRITISH ASSOCIATION SCREW THREADS—47½-DEGREE ANGLE

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Designating Number	Pitch, mm.	Approx. No. of Threads per Inch	Tolerances (See Note A)		Full Diameter, in Millimeters			Effective Diameter, in Millimeters			Core Diameter, in Millimeters			Grade	Maximum Play Permissible
			Pitch, Mm.	Angle, Deg.	Max.	Tol.	Min.	Max.	Tol.	Min.	Max.	Tol.	Min.	Hundredths of a mm.	Hundredths of a mm.
0	1.00	25.4	0.020	5.5	6.000	0.150	5.850	5.400	0.100	5.300	4.800	0.200	4.600	20.0	10.0
1	0.90	28.2	0.020	5.6	5.300	0.135	5.165	4.760	0.090	4.670	4.220	0.185	4.035	18.5	9.0
2	0.81	31.3	0.020	5.8	4.700	0.120	4.580	4.215	0.085	4.130	3.730	0.170	3.560	17.0	8.5
3	0.73	34.8	0.015	5.9	4.100	0.110	3.990	3.660	0.080	3.580	3.220	0.155	3.065	15.5	8.0
4	0.66	38.5	0.015	6.1	3.600	0.100	3.500	3.205	0.075	3.130	2.810	0.145	2.665	14.5	7.5
5	0.59	43.1	0.015	6.3	3.200	0.090	3.110	2.845	0.070	2.775	2.490	0.135	2.355	13.5	7.0
6	0.53	47.9	0.015	6.4	2.800	0.080	2.720	2.480	0.060	2.420	2.160	0.125	2.035	12.5	6.0
7	0.48	52.9	0.015	6.7	2.500	0.070	2.430	2.210	0.060	2.150	1.920	0.115	1.805	11.5	6.0
8	0.43	59.1	0.010	6.9	2.200	0.065	2.135	1.940	0.055	1.885	1.680	0.110	1.570	11.0	5.5
9	0.39	65.1	0.010	7.2	1.900	0.060	1.840	1.665	0.050	1.615	1.430	0.100	1.330	10.0	5.0
10	0.35	72.6	0.010	7.5	1.700	0.055	1.645	1.490	0.050	1.440	1.280	0.095	1.185	9.5	5.0
11	0.31	81.9	0.010	8.0	1.500	0.045	1.455	1.315	0.045	1.270	1.130	0.090	1.040	9.0	4.5
12	0.28	90.7	0.010	8.0	1.300	0.040	1.260	1.130	0.040	1.090	0.960	0.085	0.875	8.5	4.0
13	0.25	102.0	0.010	8.0	1.200	0.040	1.160	1.050	0.040	1.010	0.900	0.080	0.820	8.0	4.0
14	0.23	110.0	0.010	8.0	1.000	0.035	0.965	0.860	0.040	0.820	0.720	0.075	0.645	7.5	4.0
15	0.21	121.0	0.010	8.0	0.900	0.030	0.870	0.775	0.035	0.740	0.650	0.075	0.575	7.5	3.5

NOTE A.—Columns 4 and 5 give the errors in pitch per length of thread engaged and angle respectively, which can each be compensated by half the tolerance on effective diameter given in column 10. The errors in pitch and angle shown in the table may exist together, provided the effective diameter is reduced by the full tolerance shown in column 10. The permissible error in pitch may be increased up to double the value shown, provided the error in angle is correspondingly reduced and *vice versa*.

War Emergency Tolerances—August, 1940

To facilitate production, tolerance is increased on the minor (core) diameter of internal threads. This now equals 0.35 × pitch and permits a larger tap drill. If full advantage of these tolerances is taken, the crests of the threads will be flat. These emergency tolerances are shown on Pages 41*a* and 41*b*.

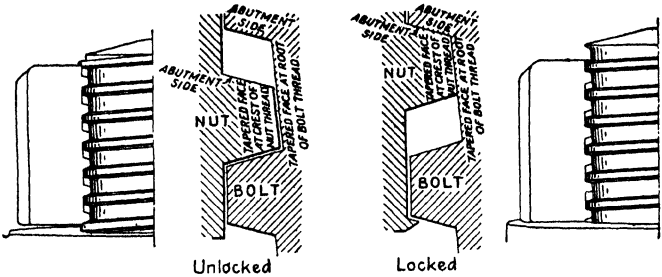
Limits and Tolerances for Bolts in Approximate Inch Equivalents

1	2	3	4	5	6	7	8	9	10	11
Designating Number	Approximate No. of Threads per Inch	Major (Full) Diameter, in Inches			Effective Diameter, in Inches			Minor (Core) Diameter, in Inches		
		Max.	Tol.	Min.	Max.	Tol.	Min.	Max.	Tol.	Min.
0	25.4	0.2362	0.0059	0.2303	0.2126	0.0039	0.2087	0.1890	0.0079	0.1811
1	28.2	0.2087	0.0053	0.2034	0.1874	0.0035	0.1839	0.1661	0.0073	0.1588
2	31.3	0.1850	0.0047	0.1803	0.1659	0.0033	0.1626	0.1468	0.0067	0.1401
3	34.8	0.1614	0.0043	0.1571	0.1441	0.0032	0.1409	0.1268	0.0061	0.1207
4	38.5	0.1417	0.0039	0.1378	0.1262	0.0030	0.1232	0.1106	0.0057	0.1049
5	43.1	0.1260	0.0036	0.1224	0.1120	0.0028	0.1092	0.0980	0.0053	0.0927
6	47.9	0.1102	0.0031	0.1071	0.0976	0.0024	0.0952	0.0850	0.0049	0.0801
7	52.9	0.0984	0.0027	0.0957	0.0870	0.0024	0.0846	0.0756	0.0045	0.0711
8	59.1	0.0866	0.0026	0.0840	0.0764	0.0022	0.0742	0.0661	0.0043	0.0618
9	65.1	0.0748	0.0024	0.0724	0.0656	0.0020	0.0636	0.0563	0.0039	0.0524
10	72.6	0.0669	0.0022	0.0647	0.0587	0.0020	0.0567	0.0504	0.0037	0.0467

LIMITS AND TOLERANCES FOR NUTS IN APPROXIMATE INCH EQUIVALENTS

1	2	3	4	5	6	7	8	9	10	11
Designating Number	Approximate No. of Threads per Inch	Major (Full) Diameter, in Inches			Effective Diameter, in Inches			Minor (Core) Diameter,* in Inches		
		Min.	*Tol.	Max.	Min.	Tol.	Max.	Min.	Tol.	Max.
0	25.4	0.2362	0.0079	0.2441	0.2126	0.0039	0.2165	0.1890	0.0138	0.2028
1	28.2	0.2087	0.0073	0.2160	0.1874	0.0035	0.1909	0.1661	0.0124	0.1785
2	31.3	0.1850	0.0067	0.1917	0.1659	0.0033	0.1692	0.1468	0.0112	0.1580
3	34.8	0.1614	0.0061	0.1675	0.1441	0.0032	0.1473	0.1268	0.0100	0.1368
4	38.5	0.1417	0.0057	0.1474	0.1262	0.0030	0.1292	0.1106	0.0091	0.1197
5	43.1	0.1260	0.0053	0.1313	0.1120	0.0028	0.1148	0.0980	0.0081	0.1061
6	47.9	0.1102	0.0049	0.1151	0.0976	0.0024	0.1000	0.0850	0.0073	0.0923
7	52.9	0.0984	0.0045	0.1029	0.0870	0.0024	0.0894	0.0756	0.0067	0.0823
8	59.1	0.0866	0.0043	0.0909	0.0764	0.0022	0.0786	0.0661	0.0059	0.0720
9	65.1	0.0748	0.0039	0.0787	0.0656	0.0020	0.0676	0.0563	0.0053	0.0616
10	72.6	0.0669	0.0037	0.0706	0.0587	0.0020	0.0607	0.0504	0.0047	0.0551

* **MINOR DIAMETER.**—The tolerances given in the above table for the minor diameter are the approximate inch equivalents of the increased tolerances permitted by this war emergency revision as given in millimeters.


ABUTMENT SIDE
ABUTMENT SIDE
NUT
TAPERED FACE AT CREST OF NUT THREAD
TAPERED FACE AT ROOT OF BOLT THREAD
BOLT
ABUTMENT SIDE
ABUTMENT SIDE
NUT
TAPERED FACE AT CREST OF NUT THREAD
TAPERED FACE AT ROOT OF BOLT THREAD
BOLT

Unlocked Locked

Dardelet Self-locking Thread

TABLE 29.—THREAD DATA

Dardelet Thread

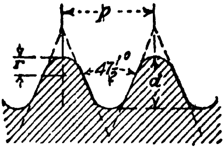
Identification		Tap Drill		Area of Body of Bolt	Minimum Diameter	Basic Area of Minimum Section Dardelet Thread
Sizes	Threads per Inch	Mark	Diameter			
1/4	16	No. 5	0.205	0.0491	0.2125	0.0355
5/16	14	G	0.261	0.0767	0.2697	0.0571
3/8	12	O	0.316	0.1105	0.3250	0.0830
7/16	11	V	0.377	0.1503	0.3829	0.1152
1/2	10	27/64	0.422	0.1964	0.4400	0.1520
9/16	9	31/64	0.484	0.2485	0.4959	0.1931
5/8	8	17/32	0.531	0.3068	0.5500	0.2376
3/4	8	21/32	0.656	0.4418	0.6750	0.3578
7/8	7	25/32	0.781	0.6013	0.7893	0.4893
1	6	57/64	0.891	0.7854	0.9000	0.6362
1 1/8	5	63/64	0.984	0.9940	1.0050	0.7933
1 1/4	5	1 1/8	1.125	1.2272	1.1300	1.0029
1 1/2	4	1 11/32	1.344	1.7671	1.3500	1.4314

The Dardelet thread resembles the Acme thread but the thread depth is less and both the root of the thread on the bolt and the crest of the thread in the nut are tapered about 6 degrees; considerable end play is provided to permit the tapered surfaces to lock, as shown.

WATCH SCREW THREADS

Watch screw threads are of sharp V form and, generally, 45-degree angle for screws used in nickel and brass but are 60 degrees for use in steel. The Waltham Watch Company and others use the centimeter as the unit for all measurements with the exception of the pitch, which is based on the inch; the Waltham threads being 110, 120, 140, 160, 170, 180, 200, 220, 240, 254 per inch and the diameters ranging from 0.120 to 0.035 centimeter. (See pages 44–46.)

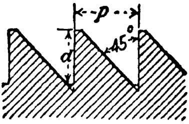
British Association Standard



p = pitch.
d = depth = $p \times 0.6$.
r = radius = $\frac{2 \times p}{11}$.

This thread has been adopted in England for small screws used by opticians and in telegraph work, upon recommendations made by the committee of the British Association. It was derived from the Swiss thread of Prof. Thury. The diameter and pitches in this system are in millimeters.

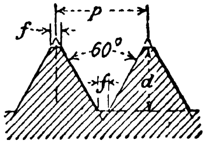
Buttress



p = pitch = $\frac{1}{\text{no. threads per inch}}$.
d = depth = $\frac{3}{4}\,p$.

The buttress thread takes a bearing only on the straight side and is very strong in that direction. The ratchet thread is of practically the same form but sharper.

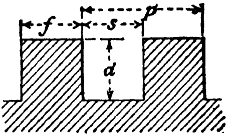
International (Metric) Standard



p = pitch.
d = depth = $p \times 0.6495$.
f = flat = $\frac{p}{8}$.

The International thread is of the same form as the American. This system was recommended by a Congress held at Zurich in 1898, and is much the same as the metric system of threads generally used in France. The sizes and pitches in the system are in millimeters. Used on spark plugs in this country.

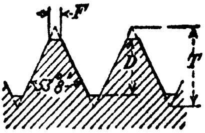
Square



p = pitch = $\frac{1}{\text{no. threads per inch}}$.
d = depth = $\frac{1}{2}\,p$.
f = width of flat = $\frac{1}{2}\,p$.
s = width of space = $\frac{1}{2}\,p$.

While theoretically depth, width of space and thread arc each one-half the pitch, in practice the groove is cut slightly wider and deeper.

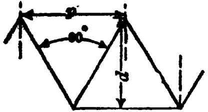
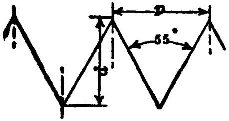
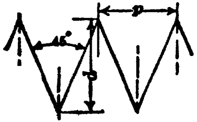
Loewenherz-German



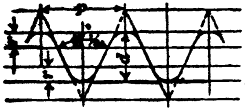
Used on the Continent for watch and instrument. Used in the United States on magnetos. It is being replaced by 60-degree metric thread.
Pitch in millimeters

$D = \frac{3}{4}\,T$.
F = flat = $0.0049 \times$ pitch in millimeters.

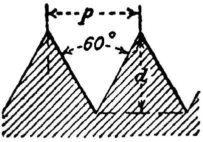
PROPERTIES OF WATCH SCREW THREADS

	Theoretical formulæ	Theoretical formulæ for double depth	Working formulæ for double depth	
60° V-Thread 	$P = \frac{1}{\text{No. of threads}}$ $d = P \times .866$	$d = \frac{1.732}{\text{No. of threads}}$	$d = \frac{1.4}{\text{No. of threads}}$	Used by E. Howard for machine shop screws and for 240 and 320 threads per inch special watch screws. This was old standard but is being replaced by U. S. form of thread.
55° V-Thread 	$P = \frac{1}{\text{No. of threads}}$ $d = P \times .9605$	$d = \frac{1.92098}{\text{No. of threads}}$	$d = \frac{1.532}{\text{No. of threads}}$	New York Standard Watch Works screw thread.
45° V-Thread 	$P = \frac{1}{\text{No. of threads}}$ $D = P \times 1.2071$	$d = \frac{2.4142}{\text{No. of threads}}$	$d = \frac{1.732}{\text{No. of threads}}$	E. Howard watch screws. Used in most American watch factories.

PROPERTIES OF WATCH SCREW THREADS—*Continued*

Thury's Swiss Thread  	$P = \frac{1}{\text{No. of threads}}$ $d = P \times .6$ $r = \frac{P}{6}$ $r' = \frac{P}{5}$	$d = \frac{1.2}{\text{No. of threads}}$	$d = \frac{1.15}{\text{No. of threads}}$	Developed by Prof. Thury of Geneva, Switzerland. Used for Swiss watch stems, also for some watch screws. E. Howard used for balance screws. Keystone Watch Case Co. uses U. S. form of thread for stems. British association thread, page 41 is similar to Prof. Thury's thread and is used in England, for clocks and small instruments.

Working formulæ are approximate for small threads.

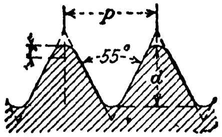


V, 60-Degree Sharp

$$p = \text{pitch} = \frac{1}{\text{no. threads per inch}}.$$

$$d = \text{depth} = p \times 0.8660.$$

While the sharp V form gives a deeper thread than the U. S. Standard, the objections urged against the thread are that the sharp top is injured by the slightest accident, and, in the case of taps and dies, the fine edge is quickly lost, causing constant variation in fitting.



Whitworth Standard

$$p = \text{pitch} = \frac{1}{\text{no. threads per inch}}.$$

$$d = \text{depth} = p \times 0.64033.$$

$$r = \text{radius} = p \times 0.1373.$$

The Whitworth thread is the standard in use in England. It was devised by Sir Joseph Whitworth in 1841, the system then proposed by him being slightly modified in 1857 and 1861.

ACME THREADS

The Acme 29-degree thread has largely replaced the square thread. Finer pitches are being used to conserve strength, decrease the tapping difficulties, and increase the bearing area in the nut. The Greenfield Tap & Die Corp. shows this clearly in Fig. 3 with the sections of both 2½- and 5-pitch threads.

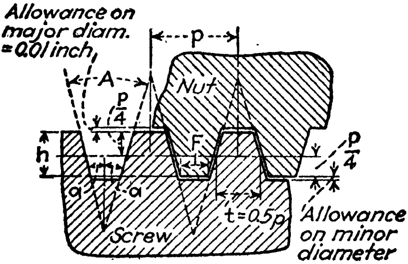

Allowance on major diam. = 0.01 inch
p
A
p/4
Nut
h
F
a
a
t = 0.5p
Screw
p/4
Allowance on minor diameter

FIG. 3.—American National Acme Thread

DEFINITIONS OF THREAD PARTS

Angle of Thread.—The angle between the sides of the thread measured in an axial plane shall be 29 degrees. The line bisecting this 29-degree angle shall be perpendicular to the axis of the screw thread.

Depth of Thread.—The basic depth of the thread shall be equal to one-half of the pitch.

Thickness of Thread.—The basic thickness of the thread at a diameter smaller by one-half the pitch than the basic major diameter shall be equal to one-half of the pitch.[11]

Clearance at Minor Diameter.—A clearance shall be provided at the minor diameter by making the minor diameter of the screw 0.010 inch smaller than basic for 10 or less threads per inch and 0.005 inch smaller than basic for more than 10 threads per inch.

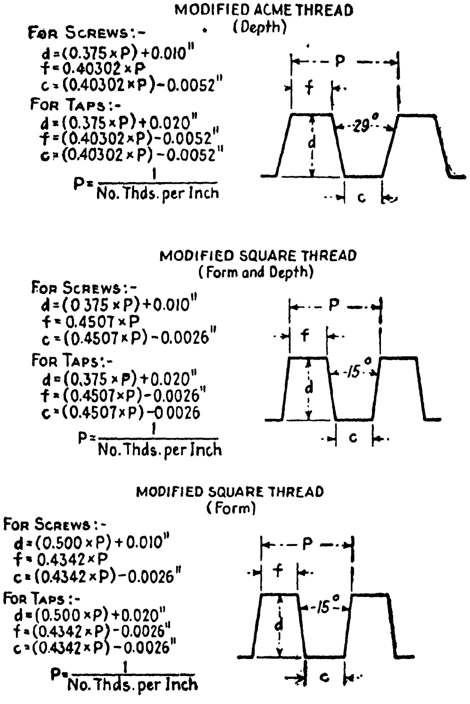


FIG. 4.—Modified Threads for Heavy Threading with Taps and Dies Suggested by Landis Machine Company, Inc.

Clearance at Major Diameter.—A clearance shall be provided at the major diameter for all classes by making the major diameter of the nut or threaded hole at least 0.020 inch larger than basic.

Fillets at Minor Diameter.—Fillets at the juncture of sides and root of the thread of the screw will develop on account of the rounding of the corners of the threading tool and the side cutting action of milling cutters when these threads are milled. It will be necessary, therefore, on tapped holes for all classes of fits, to provide a

TABLE 30.—AMERICAN NATIONAL ACME GENERAL PURPOSE THREAD SERIES

Identification		Basic Diameters			Thread Data						
Sizes	Threads per Inch	Major Diameter, *D*, in Inches	Pitch Diameter, *E*, in Inches	Minor Diameter, *K*, in Inches	Pitch, *p*, in Inches	Thread Thickness at Pitch Line, in Inches	Basic Depth of Thread, $h = 0.5p$, in Inches	Depth of Thread with Clearance, in Inches	Basic Width of Flat, $F = 0.37069p$, in Inches	Helix Angle at Basic Pitch Diameter, *s*	
1	2	3	4	5	6	7	8	9	10	11	
										Deg.	Min.
1/4	16	0.2500	0.2187	0.1875	0.06250	0.03125	0.03125	0.03625	0.0232	5	12
5/16	14	0.3125	0.2768	0.2411	0.07143	0.03571	0.03571	0.04071	0.0265	4	42
3/8	12	0.3750	0.3333	0.2816	0.08333	0.04167	0.04167	0.04667	0.0309	4	33
7/16	12	0.4375	0.3958	0.3541	0.08333	0.04167	0.04167	0.04667	0.0309	3	50
1/2	10	0.5000	0.4500	0.4000	0.10000	0.05000	0.05000	0.06000	0.0371	4	3
5/8	8	0.6250	0.5625	0.5000	0.12500	0.06250	0.06250	0.07250	0.0463	4	3
3/4	8	0.7500	0.6875	0.6250	0.12500	0.06250	0.06250	0.07250	0.0463	3	19
7/8	8	0.8750	0.8125	0.7500	0.12500	0.06250	0.06250	0.07250	0.0463	2	48
1	5	1.0000	0.9000	0.8000	0.20000	0.10000	0.10000	0.11000	0.0741	4	3
1 1/8	5	1.1250	1.0250	0.9250	0.20000	0.10000	0.10000	0.11000	0.0741	3	33
1 1/4	5	1.2500	1.1500	1.0500	0.20000	0.10000	0.10000	0.11000	0.0741	3	10
1 3/8	5	1.3750	1.2750	1.1750	0.20000	0.10000	0.10000	0.11000	0.0741	2	52
1 1/2	4	1.5000	1.3750	1.2500	0.25000	0.12500	0.12500	0.13500	0.0927	3	19
1 3/4	4	1.750	1.6250	1.5000	0.25000	0.12500	0.12500	0.13500	0.0927	2	48
2	4	2.0000	1.8750	1.7500	0.25000	0.12500	0.12500	0.13500	0.0927	2	26
2 1/2	2	2.5000	2.2500	2.0000	0.50000	0.25000	0.25000	0.26000	0.1853	4	3
3	2	3.0000	2.7500	2.5000	0.50000	0.25000	0.25000	0.26000	0.1853	3	19
4	2	4.0000	3.7500	3.5000	0.50000	0.25000	0.25000	0.26000	0.1853	2	26
5	2	5.0000	4.7500	4.5000	0.50000	0.25000	0.25000	0.26000	0.1853	1	55

fillet or bevel at the minor diameter of the tap to remove the corner of the crest of the thread of the tapped hole. This fillet, or bevel, should be at least 0.010 inch for pitches of 3 threads per inch and finer, and at least 0.020 inch for pitches coarser than 3 threads per inch.

The basic form of this thread is shown in Fig. 3. Modified forms of Acme threads used are shown in Fig. 4.

TABLE 31.—RECOMMENDED PITCHES, CORRESPONDING RANGE OF MAJOR DIAMETERS, AND BASIC THREAD DATA, AMERICAN NATIONAL ACME THREADS

Number of Threads per Inch, n	Recommended Range of Major Diameters,[1] in Inches		Pitch, p in Inches	Basic Depth of Thread, $h = 0.5p$ in Inches	Basic Width of Flat, $F = 0.37069p$ in Inches
	Least	Greatest			
1	2	3	4	5	6
1	4.5000	13.5000	1.00000	0.5000	0.3707
1⅓	3.5000	10.5000	0.75000	0.3750	0.2780
1½	3.0000	9.0000	0.66667	0.3333	0.2471
2	2.2500	6.7500	0.50000	0.2500	0.1853
2½	1.7500	5.2500	0.40000	0.2000	0.1483
3	1.5000	4.5000	0.33333	0.1667	0.1236
4	1.1250	3.3750	0.25000	0.1250	0.0927
5	0.8750	2.6250	0.20000	0.1000	0.0741
6	0.7500	2.2500	0.16667	0.0833	0.0618
8	0.5625	1.6875	0.12500	0.0625	0.0463
10	0.4375	1.3125	0.10000	0.0500	0.0371
12	0.3750	1.1250	0.08333	0.0417	0.0309
14	0.3125	0.9375	0.07143	0.0357	0.0265
16	0.2500	0.7500	0.06250	0.0312	0.0232

[1] These recommended least diameters correspond to a maximum helix angle (at the minor diameter) of approximately 5°. The recommended greatest diameter are 3 times the least.

The following general specifications apply to all standard Acme screw threads:

1. *Basic Diameters.*—The maximum major and pitch diameters of the screw, and the minimum minor diameter of the nut are basic.

2. *Tolerances.*—*a.* The tolerances specified represent the extreme variations allowed on the product.

b. The tolerances on diameters of the nuts or threaded holes are plus, and are applied from the minimum nut sizes to above the minimum nut sizes.

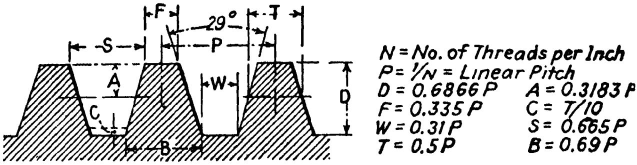
c. The tolerances on diameters of the screws are minus, and are applied from the maximum screw sizes to below the maximum screw sizes.

TABLE 32.—AMERICAN NATIONAL ACME GENERAL PURPOSE THREAD SERIES, LIMITING DIMENSIONS AND TOLERANCES

Sizes	Threads per Inch	Screw Sizes, in Inches							Nut Sizes, in Inches					
		Major Diameter		Pitch Diameter		Toler-ance Equiva-lent on Thick-ness of Threads	Minor Diameter		Minor Diameter		Pitch Diameter		Toler-ance Equiva-lent on Thick-ness of Threads	Major Diam-eter, Mini-mum
		Maxi-mum (Basic)	Mini-mum	Maxi-mum (Basic)	Mini-mum		Maxi-mum	Mini-mum	Mini-mum (Basic)	Maxi-mum	Mini-mum	Maxi-mum		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1/4	16	0.2500	0.2469	0.2187	0.2107	0.002	0.1775	0.1744	0.1875	0.1906	0.2267	0.2347	0.002	0.2600
5/16	14	0.3125	0.3089	0.2768	0.2688	0.002	0.2311	0.2275	0.2411	0.2447	0.2847	0.2928	0.002	0.3225
3/8	12	0.3750	0.3708	0.3333	0.3213	0.003	0.2816	0.2774	0.2816	0.2858	0.3453	0.3573	0.003	0.3850
7/16	12	0.4375	0.4333	0.3958	0.3838	0.003	0.3441	0.3399	0.3541	0.3583	0.4078	0.4198	0.003	0.4475
1/2	10	0.5000	0.4950	0.4500	0.4380	0.003	0.3800	0.3750	0.4000	0.4050	0.4620	0.4740	0.003	0.5200
5/8	8	0.6250	0.6187	0.5625	0.5465	0.004	0.4800	0.4737	0.5000	0.5063	0.5785	0.5945	0.004	0.6450
3/4	8	0.7500	0.7437	0.6875	0.6715	0.004	0.6050	0.5987	0.6250	0.6313	0.7035	0.7195	0.004	0.7700
7/8	8	0.8750	0.8687	0.8125	0.7965	0.004	0.7300	0.7237	0.7500	0.7563	0.8285	0.8445	0.004	0.8950
1	5	1.0000	0.9900	0.9000	0.8800	0.005	0.7800	0.7700	0.8000	0.8100	0.9200	0.9400	0.005	1.0200
1 1/8	5	1.1250	1.1150	1.0250	1.0050	0.005	0.9050	0.8950	0.9250	0. 350	1.0450	1.0650	0.005	1.1450
1 1/4	5	1.2500	1.2400	1.1500	1.1260	0.006	1.0300	1.0200	1.0500	1.0600	1.1740	1.1980	0.006	1.2700
1 3/8	5	1.3750	1.3650	1.2750	1.2510	0.006	1.1550	1.1450	1.1750	1.1850	1.2990	1.3230	0.006	1.3950
1 1/2	4	1.5000	1.4875	1.3750	1.3470	0.007	1.2300	1.2175	1.2500	1.2625	1.4030	1.4310	0.007	1.5200
1 3/4	4	1.7500	1.7375	1.6250	1.5980	0.007	1.4800	1.4675	1.5000	1.5125	1.6530	1.6810	0.007	1.7700
2	4	2.0000	1.9875	1.8750	1.8430	0.008	1.7300	1.7175	1.7500	1.7625	1.9070	1.9390	0.008	2.0200
2 1/2	2	2.5000	2.4800	2.2500	2.2060	0.011	1.9800	1.9600	2.0000	2.0200	2.2940	2.3380	0.011	2.5200
3	2	3.0000	2.9800	2.7500	2.7060	0.011	2.4800	2.4600	2.5000	2.5200	2.7940	2.8380	0.011	3.0200
4	2	4.0000	3.9800	3.7500	3.7060	0.011	3.4800	3.4600	3.5000	3.5200	3.7940	3.8380	0.011	4.0200
5	2	5.0000	4.9800	4.7500	4.7060	0.011	4.4800	4.4600	4.5000	4.5200	4.7940	4.8380	0.011	5.0200

WORM AND BUTTRESS THREADS

Worm threads also have a 29-degree angle but are 0.1766 inch deeper than the Acme on a 1-inch pitch. The proportions are



$$\text{Pitch} = \frac{1}{\text{No. of Threads per inch}}.$$

$$\text{Depth of Thread} = \frac{.6866}{\text{No. of Threads per inch}}$$

FIG. 5.—Proportions of Brown and Sharpe worm thread

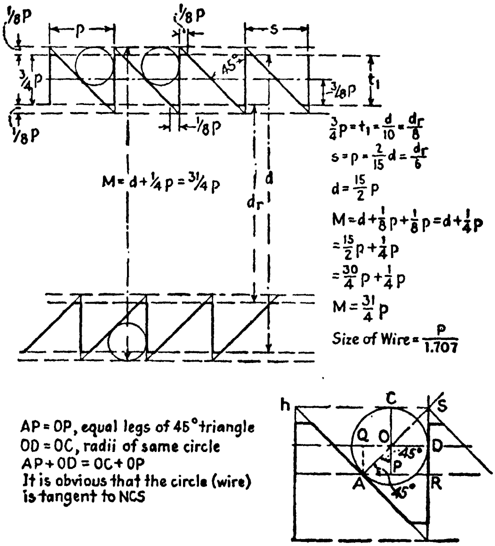


FIG. 6.—Proportions of Buttress Threads

shown in Fig. 5. The worm thread is based on the linear pitch of the worm, the proportions being figured as for a rack tooth with varying clearances at the bottom. Brown and Sharpe worm thread has a uniform clearance of 0.005 inch for all pitches.

MEASUREMENT OF THREAD TOOLS

The table of angle measurements that follows should prove of convenience to all who make tools for cutting angles or make the gages for these tools.

The principle here adopted is that, on account of the difficulty, and in some cases the impossibility, of measuring the tool at its point, the measurement is taken on the angle of the tool at a given distance from the point. In this case the true measurement will be less than the actual measurement by an amount equal to twice the tangent of half of the angle, multiplied by the distance of the line of measurement from the point.

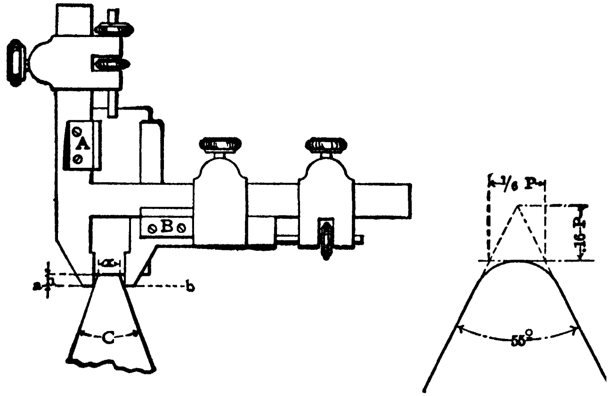


FIG. 7.—Measuring Thread Tools with Vernier Caliper

For making the measurement the Brown and Sharpe gear-tooth caliper may be used. Figure 7 shows this tool in position for measuring. The depth vernier *A* is set to a given depth *h*, and the measurement is taken by means of the vernier *B*. The width of the tool point *x* is equal to the measurement on the line *a b* less $2h\left(\tan\frac{C}{2}\right)$. To use the table, *h* is always taken to be $\frac{1}{16}$ inch, which is found to be a convenient depth for most work. If a greater depth is required, all that is necessary is to multiply the figures given by the ratio of the required depth to $\frac{1}{16}$ inch. For instance, if the depth is required to be $\frac{1}{8}$ inch, the figures given are multiplied by 2. In the great majority of cases, $\frac{1}{16}$ will be found a suitable value for *h*, when to find the width of the point *x* it is merely necessary to deduct the value of $\frac{\tan\frac{C}{2}}{8}$ for the angle required, which can be obtained at a glance from the table.

In the case of the American or United States standard thread, the point of the tool should be one-eighth of the pitch of the screw, while in the Whitworth standard, as shown, the point of the tool would be one-sixth of the pitch if it were not rounded. By using these figures in combination with the table, it can be determined when sufficient has been ground from the point of the tool.

The table is called "Table for Angle Measurements," because if a sharp angle, that is, one without the point ground away, is measured as above, this measurement, by reference to the table, will give the angle direct.

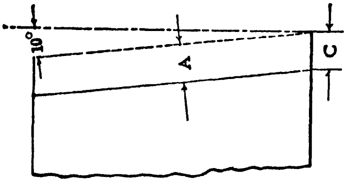
TABLE 33.—THREAD TOOL ANGLE MEASUREMENTS

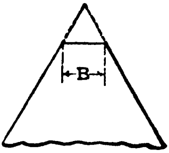
Degrees	$\frac{\tan \frac{C}{2}}{8}$	Degrees	$\frac{\tan \frac{C}{2}}{8}$	Degrees	$\frac{\tan \frac{C}{2}}{8}$
1	0.0011	31	0.0346	61	0.0736
2	0.0022	32	0.0358	62	0.0751
3	0.0033	33	0.0370	63	0.0766
4	0.0044	34	0.0382	64	0.0781
5	0.0055	35	0.0394	65	0.0796
6	0.0066	36	0.0406	66	0.0811
7	0.0077	37	0.0418	67	0.0827
8	0.0088	38	0.0430	68	0.0843
9	0.0099	39	0.0442	69	0.0859
10	0.0110	40	0.0454	70	0.0875
11	0.0121	41	0.0466	71	0.0891
12	0.0132	42	0.0489	72	0.0908
13	0.0143	43	0.0492	73	0.0925
14	0.0154	44	0.0505	74	0.0942
15	0.0165	45	0.0518	75	0.0959
16	0.0176	46	0.0531	76	0.0976
17	0.0187	47	0.0544	77	0.0994
18	0.0198	48	0.0557	78	0.1012
19	0.0209	49	0.0570	79	0.1030
20	0.0220	50	0.0583	80	0.1048
21	0.0231	51	0.0596	81	0.1067
22	0.0242	52	0.0609	82	0.1086
23	0.0253	53	0.0623	83	0.1105
24	0.0264	54	0.0637	84	0.1125
25	0.0275	55	0.0651	85	0.1145
26	0.0286	56	0.0665	86	0.1165
27	0.0298	57	0.0679	87	0.1186
28	0.0310	58	0.0693	88	0.1207
29	0.0322	59	0.0707	89	0.1228
30	0.0334	60	0.0721	90	0.1250

GRINDING THE FLAT ON THREAD TOOLS

To facilitate grinding the correct width of flat for the single-point inserted tool to cut American standard form of threads, the table

TABLE 34.—ELEMENTS OF GRINDING FLAT END OF TOOL FOR AMERICAN FORM OF THREAD, GIVING DEPTH AND FLAT





Threads per Inch	Pitch	A	B	C	Double Depth	Depth
1	1.000	.1064	.125	.1082	1.299	.6495
2	.5000	.0532	.0625	.0541	.6495	.3247
3	.3333	.0355	.0416	.0360	.433	.2165
4	.2500	.0266	.0312	.0270	.3247	.1623
5	.2000	.0213	.0250	.0216	.2598	.1299
6	.1666	.0177	.0208	.0180	.2165	.1082
7	.1428	.0152	.0178	.0154	.1855	.0927
8	.1250	.0133	.0156	.0135	.1623	.0812
9	.1111	.0118	.0138	.0120	.1443	.0721
10	.1000	.0106	.0125	.0108	.1299	.0649
11	.0909	.00963	.0113	.0098	.1180	.0592
12	.0833	.00886	0104	.0090	.1082	.0541
13	.0769	.00818	.0096	.0083	.0999	.0499
14	.0714	.00758	.0089	.0077	.0920	.0460
15	.0666	.00707	.0083	.0071	.0866	.0433
16	.0625	.00673	.0079	.0068	.0812	.0406
17	.0588	.00620	.0073	.0063	.0764	.0382
18	.0555	.00588	.0069	.0059	.0721	.0360
19	.0526	.00554	.0065	.0056	.0683	.0341
20	.0500	.00530	.0062	.0054	.0649	.0324
21	.0476	.00503	.0059	.0051	.0618	.0309
22	.0454	.0048	.0056	.0049	.0590	.0295
23	.0431	.00451	.0053	.0046	.0564	.0282
24	.0416	.00433	.0052	.0045	.0541	.0270
25	.0400	.00426	.0050	.0043	.0519	.0259
26	.0384	.00409	.0048	.0041	.0491	.0245
27	.0370	.00393	.0046	.0040	.0481	.0240
28	.0357	.00375	.0044	.0038	.0463	.0231
29	.0344	.00366	.0043	.0037	.0447	.0223
30	.0333	.00354	.0041	.0036	.0433	.0216
31	.0322	.00341	.0040	.0035	.0419	.0209
32	.0312	.00332	.0039	.0034	.0405	.0202

on page 54 shows flats for commonly used threads. The distance from the point of the tool to the back is first measured with the micrometer, then the point of the tool may be ground off until the micrometer measurement from the back is equal to the whole depth minus dimension *A*, when we may be sure, without undertaking the difficult job of measuring it directly, that the flat *B* has the proper width. The dimensions *A* and *B* for pitches from 1 to 32 threads per inch are included in the table.

SCREW-THREAD MEASUREMENT

Screw threads are no longer measured by their outside diameter, but by the pitch diameter, using either micrometers with special points that bear only on the thread angle, wires laid in the threads and measured across the outside, or optical methods that compare a magnified image of the thread with a standard pattern. The first two methods are more common than the last, although the optical method is being more widely used.

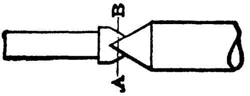


FIG. 8.—Spindle and Anvil of Thread Micrometer

Screw-Thread Micrometer Caliper

The thread micrometer is fitted with pointed spindle and V anvil, as in Fig. 8, to measure the actual thread on the cut surface. Enough of the point is removed and the bottom of the V is carried low enough so that the anvil and spindle clear the top and bottom of the thread and rest directly on the sides of the thread.

As it measures one-half of the depth of the thread from the top, on each side, the diameter of the thread, as indicated by the caliper, is the pitch diameter, or the full size of the piece less the depth of one thread. See tables on pages 61 and 62.

This depth may be found as follows:

Depth of V threads = 0.866 ÷ number of threads to 1 inch.

Depth of American threads = 0.6495 ÷ number of threads to 1 inch.

Depth of Whitworth threads = 0.64 ÷ number of threads to 1 inch.

As the American thread is flattened one-eighth of its own depth on top, it follows that the minor diameter of the thread is increased one-eighth on each side, equaling one-fourth of the whole depth and, instead of the constant 0.866, we use the constant 0.6495, which is three-fourths of 0.866.

When the point and anvil are in contact, the 0 represents a line drawn through the plane *AB*, Fig. 8, and if the caliper is opened, say to 0.500, it represents the distance of the two planes 0.500 inch apart. The pitch diameters of standard threads are given on pages 8–9. British tables call this "effective diameter."

Measuring Threads by the Three-Wire Method

The three-wire method of measuring the pitch diameter of screws is recommended by the Bureau of Standards as the best means of securing uniformity. By placing the three wires, of correct diameter, in the threads, as shown in Fig. 9, and measuring over them, the pitch diameter can be found directly by subtracting the wire constant from the measured diameter. This simplified procedure results only when the "best wire" for the pitch of the screw is used.

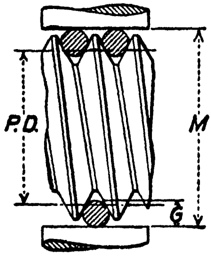


FIG. 9.—Using 3 Wires

The *best* wire is the size of wire which touches the thread at the middle of the sloping sides. Inasmuch as the *pitch diameter* is defined as the diameter of the screw where the land and space are equal (this occurs at the middle of the sloping sides), the "best wire" touches the thread at the pitch diameter. Also, measurements of pitch diameter with "best" wires are true measurements, although slight variations are present in the angle of thread.

The wires used should be hardened and lapped steel wires and should be *three* times as accurate as the accuracy of the measurements desired. Bureau of Standards specifications call for an accuracy of 0.00002 inch.

The formula for the *best* wire is:

$$G = \frac{\sec a}{2N}$$

The general formula for computing the measured pitch diameter of a screw is:

$$E = M + \frac{\cot a}{2N} - G(1 + \operatorname{cosec} a)$$

where M = measurement over wires.
E (or PD) = pitch diameter.
G = diameter of "best" wire.
N = number of threads per inch.
a = one-half of the included angle of thread.

For a 60-degree thread, which includes American coarse and National fine threads and also 60-degree metric threads, this formula reduces as follows:

$$E = M + \frac{1.73205}{2N} - G(1 + 2.00000).$$

And this reduces further to

$$E = M + \frac{0.86602}{N} - 3G.$$

Now it so happens for a 60-degree thread that the depth of a sharp V thread is $\frac{0.86602}{N}$ and that $3G$ or three times the diameter of the "best" wire is just twice $\frac{0.86602}{N}$, so the formula is further simplified to:

$$E = M - \text{depth of V thread.}$$
$$M = E + \text{depth of V thread.}$$

To check pitch diameter E from outside measurement over the wires, transpose the formula to:

$$M = E + 3G - \frac{0.86602}{N}$$

The first column on page 64 shows the number of threads per inch, the second the diameter of the best wire G to use for the different pitches, then the wire constant or depth of a V thread H, next, depth of American thread h, and the smallest and largest wires that can be used. The formula for each is given at the top of the column.

Formula for other thread angles and a clamp for holding work and wires on pages 60, 65, and 75.

MEASURING THE THREAD ANGLE

There is sometimes confusion in measuring National and V threads with the same wires. The V thread, being deeper than the National form, has a smaller pitch diameter for the same outside diameter. A ½-inch 13-pitch National, for example, has a pitch diameter of 0.45004 inch, whereas a V thread of the same outside diameter has a pitch diameter of 0.43338 inch.

The angle of thread can be checked by using wires of two sizes and measuring over each, then calculated by the following formula. Using the maximum wire G_1 and the minimum wire G_2 and calling the maximum measurement M_1 and the minimum measurement M_2, the formula is $\frac{M_1 - M_2}{G_1 - G_2}$. When this equals 3.0000, the angle is 60 degrees. For other angles the following results will be obtained:

The following is an example of measuring a ½-inch 13-pitch American coarse thread:

Major diameter	0.5000 inch
Number threads per inch	13
Best wire size	0.04441 inch
Measurement over wires	0.5169 inch
Wire constant	0.06662 inch
G_1 maximum wire size	0.06415 inch
G_2 minimum wire size	0.04124 inch
M_1 measurement over maximum wires	0.5811 inch
M_2 measurement over minimum wires	0.5122 inch

The measured pitch diameter is 0.5169 − 0.06662 = 0.45028 inch.

The nominal or basic pitch diameter should be specified on the shop drawing, but if not, it is found by subtracting the depth of thread h from the major diameter. Thus the basic pitch diameter is 0.5000 − 0.04996 = 0.45004 inch. The thread measured is, therefore, 0.00024 inch oversize.

If we substitute the measurements obtained with the maximum and minimum wires in the formula for angle, the result is:

$$\frac{0.5811 - 0.5122}{0.06415 - 0.04124} = \frac{0.0689}{0.02291} = 3.0074.$$

From the table of results of angle computations it is found that 3.0101 corresponds to an angle of 59 degrees 40 minutes and the result 3.0050 to 59 degrees 50 minutes. The result obtained in the ?-inch 13-pitch example is about halfway between 3.0101 and 3.0050, and the angle of thread is therefore 59 degrees 45 minutes.

Best Size Wires

Wires which touch the thread at the pitch diameter are known as "best size" wires. Such wires are used because the measurements of pitch diameter are least affected by errors that may be present in the angle of the thread. The diameter of the measuring wires is represented by the letter G.

The general formula for best size wires is:

$$G = \frac{\text{secant } a}{2n}$$

For 60-degree threads this reduces to

$$G = \frac{0.57735}{n} \text{ or } 0.57735p$$

For 55-degree threads best size wires

$$G = \frac{0.563692}{n} \text{ or } 0.563692p$$

For 53-degree 8-minute threads best size wires

$$G = 0.55902p$$

For 50-degree threads best size wires

$$G = \frac{0.5517}{n}$$

For 47½-degree threads best size wires

$$G = 0.54625p$$

For 40-degree threads best size wires

$$G = \frac{0.5321}{n} \text{ or } 0.5321p$$

For 29-degree threads best size wires

$$G = \frac{0.51645}{n} \text{ or } 0.51645p$$

For 60-degree threads the depth of a sharp V thread will equal 3 × (best wire diameter) except in some cases in the fifth decimal place, where computations may not be exact.

MEASURING WIRE SPECIFICATIONS

Important Specifications

2- to 20-pitch wires are standard at 2½ pounds pressure over a 0.750 diameter cylinder.

22- to 120-pitch wires are standard at 1 pound pressure over a 0.750 diameter cylinder.

Complete Specifications

The following is abstracted from the 1942 revision of "Screw Thread Standards for Federal Services:

STANDARD SPECIFICATION FOR WIRES AND STANDARD PRACTICE IN MEASUREMENT OF WIRES

The following specifications represent present practice relative to thread measuring wires:

1. **Composition.**—The wires shall be accurately finished hardened steel cylinders of the maximum possible hardness without being brittle. The hardness shall not be less than that corresponding to a Knoop indentation number of 630. A wire of this hardness can be cut with a file only with difficulty. The surface shall not be rougher than the equivalent of one measuring 3 micro-inches root mean square deviation from a true cylindrical surface, as measured with the profilometer.

2. **Construction.**—The working surface shall be at least 1 inch in length. The wire may be provided with a suitable means of suspension.

3. **Container and Marking.**—A suitable container shall be provided for each set of wires, and the pitch for which the wires are the best size and the diameter of the working part of the wires, as determined by measurements under standard conditions as specified below, shall be marked on the container.

4. **Diameter of Wires.**—One set of wires shall consist of three wires which shall have the same diameter within 0.00002 inch, and this common diameter shall be within 0.0001 inch of that corresponding to the best size for the pitch for which the wire is to be used. Wires shall be measured between a flat contact and a 0.750 inch hardened and accurately ground and lapped steel cylinder with contact pressure as follows: Wires for 60-degree threads in pitches finer than twenty threads per inch, 16 ounces; wires for pitches of twenty threads per inch and coarser, 2½ pounds, wires for 29-degree threads, 2½ pounds.

It is recommended that wires, which are used for the measurement of gears, splines, dovetails and other surfaces where the contact of the wire is a line contact, be measured between flat parallel measuring contacts under a 1-pound load.

5. **Variations in Diameter.**—Variations in diameter around the wire (roundness) shall not exceed 0.00002 inch, as determined by measuring between a flat measuring contact and a hardened and well finished 60-degree V groove cut on a cylinder. Variations in diameter along the wire (taper), over the ½-inch interval at the center of its length, shall not exceed 0.00002 inch, as determined by measuring between a flat contact and a cylindrical contact.

METHODS OF MEASURING AND USING WIRES

In order to measure the pitch diameter of a screw-thread gage to an accuracy of 0.0001 inch by means of wires, it is necessary to know the wire diameters to 0.00002 inch. The micrometer to be used for measuring wires should be one which is graduated to ten-thousands of an inch and upon which hundred-thousandths of an inch can be estimated. Such micrometers are available in various forms of precision bench micrometers, and measuring machines. Care should be taken to make sure that the measuring faces of the micrometer are flat and parallel to within 0.00002 inch. The taper of wires can best be determined by measuring between a flat micrometer contact and a cylindrical anvil. Any pits or worn spots on the wires can be detected with the same arrangement. Variations in roundness and straightness are usually determined by rotating the wire between flat contacts one-fourth inch in diameter. However, one form of variation in roundness can only be detected by rotating the wire in a V groove against a flat micrometer contact. The V groove may be the thread space in a hardened and well-finished thread plug gage.

The contact pressure used in making measurements is also an important factor, since the wires, when in use, rest on the sides of the thread, and a given pressure exerted on the top of the thread has a magnified effect in distorting the wire and causing the measurement of the pitch diameter to be slightly less than it should be. In making measurements over the wires inserted in the thread groove, it has been common shop practice to hold the wires down into the thread by means of elastic bands. This has a tendency to prevent the wires from adjusting themselves to the proper position in the thread grooves; thus a false measurement is obtained. In some cases it has also been the practice to support the screw being measured on two wires, which are in turn supported on a horizontal surface, and measuring from this surface to the top of a wire placed in a thread over the gage. If the screw is of large diameter, its weight causes a distortion of the wires and an inaccurate reading is obtained. For these reasons these practices should be avoided and subsidiary apparatus for supporting the wires and micrometer should be used.

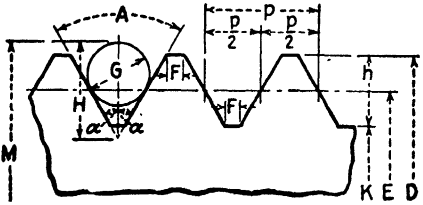
For consistent results a standard practice as to contact pressure in making wire measurements of hardened screw thread gages is necessary. The computed value for the pitch diameter of a screw thread gage obtained from readings over wires will depend upon the accuracy of the measuring instrument used, the contact pressure, and the value of the diameter of the wires used in the computations. The use of different contact pressures will cause a difference in the readings over the wires, and such errors can only be compensated by the use of a value for the diameter of the wires depending on the contact pressure used. The effect of variation in contact pressure in measuring threads of fine pitches is indicated by the difference in readings obtained with 2 and 5 pounds pressure on a 24-pitch thread plug gage. The readings over the wires with 5 pounds pressure was 0.00013 inch less than with 2 pounds pressure.

A wire presses on the sides of a 60-degree thread with the pressure that is applied to the wire by the measuring instrument. This fact would indicate that the diameter of the wire should be determined by readings made on the wire over a hardened and lapped cylinder having a radius equal to the radius of curvature of the helical surface of the thread at the point of contact, using the pressure to be used in determining the pitch diameter of the gage. However, it is not practical to employ such a variety of cylinders as would be required, and it is recommended for standard practice that wires be measured between a flat contact and a 0.750-inch hardened and accurately ground and lapped steel cylinder with the pressure used in measuring the pitch diameter of the gage. Furthermore, to avoid a permanent deformation of the material of the wires and gages it is necessary to limit the contact pressure. For pitches finer than 20 threads per inch a pressure of 14 to 16 ounces is recommended. For pitches of 20 threads per inch and coarser a pressure of 2¼ to 2½ pounds is recommended.

Measurements of a thread plug gage made in accordance with these instructions, with wires which conform to the above specifications, should be accurate to 0.0001 inch. If the diameters of the wires are known only to an accuracy of 0.0001 inch, an accuracy better than 0.0003 inch in the measurement of pitch diameter cannot be expected.

INTERNATIONAL 60-DEGREE METRIC THREADS

The international metric thread was recommended by a Congress held at Zurich in 1898, and is similar to the metric system of threads used in France. The thread form is the same as American threads. It is used in the United States for spark plug threads.



International 60° Metric Thread

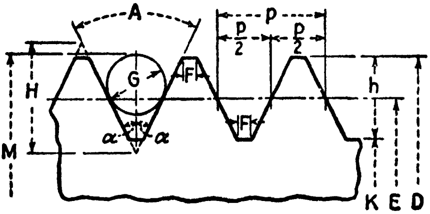
$A = 60^\circ$
$a = 30^\circ$
p = pitch in millimeters
$H = 0.86602p$
$h = 0.64952p$
$F = 0.125p$
D = basic major diameter

$E = D - h$ = pitch diameter
$K = D - 2h$ = minor diameter
$G = 0.57735p$ = diameter best wire
$E = M - \left(3G - \frac{0.86602}{n}\right)$ = measured P.D.

Lowenherz 53 Degrees, 8 Minutes

The Lowenherz thread is used in Europe for watch and instrument threads. It is used in the United States on magnetos, but it is gradually being replaced by the 60-degree metric thread.

All dimensions in millimeters



Lowenherz 53° – 8′ Thread. All Dimensions in Millimeters

$A = 53^\circ - 8'$
$a = 26^\circ - 34'$
p = pitch in millimeters
$H = p$
$h = 0.75p$ $F = \frac{p}{8}$

D = basic major diameter
$E = D - h$ = basic pitch diameter
$K = D - 2h$ = basic minor diameter
$G = 0.55902p$ = diameter best wire
$E = M - (3.23594G - p)$ = measured P.D.

TABLE 35.—BASIC DIMENSIONS OF INTERNATIONAL 60° METRIC THREADS

Millimeter Sizes					Approx. No. of Threads per Inch (n)	Equivalent Sizes in Inches			
Diam. of Screw (D)	Pitch (p)	Depth of Thread $.6495p$ (h)	Pitch Diam. $D - h$ (E)	Minor Diam. $D - 2h$ (k)		Depth of Thread $.6495p$ (h)	Major Diam. (D)	Pitch Diam. $D - h$ (E)	Minor Diam. $D - 2h$ (K)
3	0.50	0.32475	2.67525	2.350	50.8	0.01279	0.11811	0.10532	0.09253
3.5	0.60	0.38970	3.11030	2.721	42.3	0.01534	0.13780	0.12246	0.10712
4	0.70	0.45465	3.54535	3.091	36.3	0.01790	0.15748	0.13958	0.12168
4.5	0.75	0.48712	4.01288	3.526	33.9	0.01918	0.17716	0.15798	0.13880
5	0.80	0.51960	4.48040	3.961	31.8	0.02046	0.19685	0.17639	0.15593
5.5	0.90	0.58455	4.91545	4.331	28.2	0.02301	0.21654	0.19353	0.17052
6	1.00	0.64950	5.35050	4.70	25.4	0.02557	0.23622	0.21065	0.18508
7	1.00	0.64950	6.35050	5.70	25.4	0.02557	0.27559	0.25002	0.22445
8	1.25	0.81188	7.18813	6.38	20.3	0.03196	0.31496	0.28300	0.25104
9	1.25	0.81188	8.18813	7.38	20.3	0.03196	0.35433	0.32237	0.29041
10	1.5	0.97425	9.026	8.05	16.9	0.03836	0.39370	0.35534	0.31698
11	1.5	0.97425	10.026	9.05	16.9	0.03836	0.43307	0.39471	0.35635
12	1.5	0.97425	11.026	10.05	16.9	0.03836	0.47244	0.43408	0.39572
12	1.75	1.13662	10.863	9.73	14.5	0.04475	0.47244	0.42769	0.38294
14	2.0	1.2990	12.701	11.40	12.7	0.05114	0.55118	0.50004	0.44890
16	2.0	1.2990	14.701	13.40	12.7	0.05114	0.62992	0.57878	0.52764
18	2.5	1.62375	16.376	14.75	10.2	0.06393	0.70866	0.64473	0.58080
20	2.5	1.62375	18.376	16.75	10.2	0.06393	0.78740	0.72347	0.65954
22	2.5	1.62375	20.376	18.75	10.2	0.06393	0.86614	0.80221	0.73828
22	3.0	1.9485	20.052	18.10	8.5	0.07671	0.86614	0.78943	0.71272

24	3.0	1.9485	22.052	20.10	8.5	0.07671	0.94488	0.86817	0.79146
26	3.0	1.9485	24.052	22.10	8.5	0.07671	1.02362	0.94691	0.87020
27	3.0	1.9485	25.052	23.10	8.5	0.07671	1.06299	0.98628	0.90957
28	3.0	1.9485	26.052	24.10	8.5	0.07671	1.10236	1.02565	0.94894
30	3.5	2.27325	27.727	25.45	7.3	0.08950	1.18110	1.09160	1.00210
32	3.5	2.27325	29.727	27.45	7.3	0.08950	1.25984	1.17034	1.08084
33	3.5	2.27325	30.727	28.45	7.3	0.08950	1.29921	1.20971	1.12021
34	3.5	2.27325	31.727	29.45	7.3	0.08950	1.33858	1.24908	1.15958
36	4.0	2.5980	33.402	30.80	6.4	0.10228	1.41732	1.31504	1.21276
38	4.0	2.5980	35.402	32.80	6.4	0.10228	1.49606	1.39378	1.29150
39	4.0	2.5980	36.402	33.80	6.4	0.10228	1.53543	1.43315	1.33087
40	4.0	2.5980	37.402	34.80	6.4	0.10228	1.57480	1.47252	1.37024
42	4.5	2.92275	39.077	36.15	5.6	0.11507	1.65354	1.53847	1.42340
44	4.5	2.92275	41.077	38.15	5.6	0.11507	1.73228	1.61721	1.50214
45	4.5	2.92275	42.077	39.15	5.6	0.11507	1.77165	1.65658	1.54151
46	4.5	2.92275	43.077	40.15	5.6	0 11507	1.81102	1.69595	1.58088
48	5.0	3.2475	44.752	41.50	5.1	0.12785	1.88976	1.76191	1.63406
50	5.0	3.2475	46.752	43.50	5.1	0.12785	1.96850	1.84065	1.71280
52	5.0	3.2475	48.752	45.50	5.1	0.12785	2.04724	1.91939	1.79154
56	5.5	3.57225	52.428	48.86	4.6	0.14064	2.20472	2.06408	1.92344
60	5.5	3.57225	56.428	52.86	4.6	0 14064	2.36220	2.22156	2.08092
64	6.0	3.8970	60.103	56.21	4.2	0.15342	2.51968	2.36626	2.21284
68	6.0	3.8970	64.103	60.21	4 2	0.15342	2.67716	2.52374	2.37032
72	6.5	4.22175	67.778	63.56	3.9	0.16621	2.83464	2.66843	2.50222
76	6.5	4.22175	71.778	67.56	3.9	0.16621	2.99212	2.82591	2.65970
80	7.0	4.5465	75.454	70.91	3.6	0.17900	3.14960	2.97060	2.79160

Thread Formulas

The following formulas for various threads will be found useful:

Designation	Included Angle		Thread Depth	Formula for Finding Pitch Diameter with 3-Wire Method
	Deg.	Min.		
National	60		$\frac{0.649519}{n}$	$E=M-\left(3G-\frac{0.86602}{n}\right)$
National Pipe	60		$\frac{.8}{n}$	$E=1.00049M-\left(3G-\frac{0.86602}{n}\right)$
Sharp V	60		$\frac{0.86602}{n}$	$E=M-\left(3G-\frac{0.86602}{n}\right)$
International Metric	60		$\frac{0.649519}{n}$	$E=M-\left(3G-\frac{0.86602}{n}\right)$
Whitworth	55		$\frac{0.64033}{n}$	$E=M-\left(3.16568G-\frac{0.96049}{n}\right)$
British Association	47½		$6p$	$E=M-(3.4829G-1.13634p)$
Lowenherz	53	8	$.75p$	$E=M-(3.23594G-p)$
Acme Screws	29		$\frac{1}{2n}+.010$ inch	$E=M-\left(4.9939G-\frac{1.93334}{n}\right)$
Acme Taps	29		$\frac{1}{2n}+.020$ inch	$E=M-\left(4.9939G-\frac{1.93334}{n}\right)$
29-degree Worm	29		$\frac{0.6866}{n}$	Use wire $\frac{0.5149}{n}$ to come flush with top of thread.
40-degree Worm	40		$\frac{0.6866}{n}$	Use wire $\frac{0.51234}{n}$ to come flush with top of thread.

NOTES: 1. On 29- and 40-degree worm threads the addendum above the pitch diameter is $\frac{0.3183}{n}$. The thread depth of $\frac{0.6866}{n}$ provides a clearance of $\frac{0.05}{n}$ at the bottom of the thread.

2. In the above formula *G* can be any size wire that will fit in the thread.

3. Helix angle corrections are not included in the foregoing formulas.

EXAMPLE.—(USING BEST WIRES): Given a ¾ inch—10 thread, to be measured with 0.05774 inch diameter best size wires. The wire constant = 3 × 0.05774 inch − 0.08660 inch = 0.08662 inch. (See Table 38 on page 64.) The measurement over the 3 wires is found to be 0.7071 inch. Then $E = M - W = 0.7701$ inch − 0.08662 = 0.68348 inch.

From Table 2, page 9, the basic *P.D.* of a ¾ inch − 10 screw	= 0.6850
Subtract the actual *P.D.*	= 0.68348
The thread is undersize	0.00152 inch

$$50\text{-degree worm } E = M + \frac{1.0722}{n} - 3.0662G - GS^2 \times .97175$$

The ¾ inch − 10 thread is measured with 6-pitch best wires which are 0.09623 inch in diameter, and the measurement over the three wires is found to be 0.8865 inch.

Using equation (4) $E = M - (3 \times \text{diameter of wires} - \text{depth of sharp V thread})$ there results.

$E = 0.8865$ inch $- (3 \times 0.09623$ inch $- 0.08660$ inch)
$E = 0.8865$ inch $- (0.28869$ inch $- 0.08660$ inch)
$E = 0.8865$ inch $- 0.20209$ inch $= 0.68441$ inch
(See Table 47, page 83 for depth of sharp V thread.)

The basic *P.D.* of a $\frac{3}{4}$ inch $-$ 10 thread =	0.6850 inch
Subtract actual *P.D.*	0.68441 inch
The thread is undersize	0.00059 inch

It should be noted that the thread is undersize 0.00152 inch using best size wires, and undersize 0.00059 inch using the larger 6-pitch wires. This lack of agreement might be caused by the included angle of thread being less than 60 degrees. If the angle were perfect, both measurements should check.

Measuring the Included Angle of Thread with Two Sizes of Wires

To measure the angle of thread, two measurements are made with different size wires, usually as near as possible to the maximum size and minimum size wires that will fit into the thread. Table 38, page 64, gives the maximum and minimum wire sizes that can be used for any pitch of thread. For instance, on a screw of sixty-four threads per inch, the best size wires for 64 pitch are the minimum wires, and the best size wires for 40 pitch are the maximum size wires.

The general formula for determining the included angle of thread is

$$(1) \qquad \text{cosecant } a = \frac{M_1 - M_2}{G_1 - G_2} - 1$$

or

$$(2) \qquad \frac{M_1 - M_2}{G_1 - G_2} = \text{cosecant } a + 1$$

Where: M_1 = measurement over the three large size wires of diameter G_1
M_2 = measurement over the three small size wires of diameter G_2

Table 35*a* page 58*h*, gives values of (cosecant $a + 1$) for angles 2° greater and 2° less than the common angles used in screw threads.

For a thread exactly 60 degrees, the half angle (a) being 30 degrees, cosecant a = cosecant 30 degrees = 2.0000, and equation (2) becomes

$$(3) \qquad \frac{M_1 - M_2}{G_1 - G_2} = 2.0000 + 1 = 3.0000 \quad \text{(Result)}$$

TABLE 35*a*.—VALUES OF (COSECANT $a + 1$)
For Measuring Included Angle of Threads

60° Threads			55° Threads			53° 8′ Threads			47½° Threads		
°	′		°	′		°	′		°	′	
58		3.0627	53		3.2411	51	8	3.3172	45	30	3.5859
58	10	3.0573	53	10	3.2346	51	18	3.3101	45	40	3.5770
58	20	3.0519	53	20	3.2282	51	28	3.3032	45	50	3.5681
58	30	3.0466	53	30	3.2217	51	38	3.2962	46		3.5593
58	40	3.0413	53	40	3.2153	51	48	3.2894	46	10	3.5506
58	50	3.0360	53	50	3.2090	51	58	3.2825	46	20	3.5419
59		3.0308	54		3.2027	52	8	3.2757	46	30	3.5333
59	10	3.0256	54	10	3.1964	52	18	3.2690	46	40	3.5247
59	20	3.0204	54	20	3.1902	52	28	3.2623	46	50	3.5163
59	30	3.0152	54	30	3.1840	52	38	3.2556	47		3.5078
59	40	3.0101	54	40	3.1778	52	48	3.2490	47	10	3.4998
59	50	3.0050	54	50	3.1717	52	58	3.2425	47	20	3.4912
60		3.0000	55		3.1657	53	8	3.2359	47	30	3.4829
60	10	2.9950	55	10	3.1596	53	18	3.2294	47	40	3.4748
60	20	2.9900	55	20	3.1536	53	28	3.2230	47	50	3.4666
60	30	2.9850	55	30	3.1477	53	38	3.2166	48		3.4586
60	40	2.9801	55	40	3.1418	53	48	3.2103	48	10	3.4506
60	50	2 9752	55	50	3.1359	53	58	3.2039	48	20	3.4426
61		2.9703	56		3.1300	54	8	3.1977	48	30	3.4347
61	10	2.9654	56	10	3.1242	54	18	3.1914	48	40	3.4269
61	20	2.9606	56	20	3.1185	54	28	3.1852	48	50	3.4191
61	30	2.9558	56	30	3.1127	54	38	3.1791	49		3.4114
61	40	2.9510	56	40	3.1070	54	48	3.1730	49	10	3.4037
61	50	2.9463	56	50	3.1014	54	58	3.1669	49	20	3.3961
62		2.9416	57		3.0957	55		3.1608	49	30	3.3886
43		3.7285	38		4.0715	27		5.2836			
43	10	3.7185	38	10	4.0586	27	10	5.2579			
43	20	3.7085	38	20	4.0458	27	20	5.2324			
43	30	3.6986	38	30	4.0331	27	30	5.2072			
43	40	3.6888	38	40	4.0206	27	40	5.1824			
43	50	3.6791	38	50	3.0081	25	50	5.1578			
44		3.6695	39		3.9957	28		5.1336			
44	10	3.6595	39	10	3.9835	28	10	5.1096			
44	20	3.6504	39	20	3.9713	28	20	5.0859			
44	30	3.6410	39	30	3.9593	28	30	5.0625			
44	40	3.6316	39	40	3.9474	28	40	5.0394			
44	50	3.6223	39	50	3.9355	28	50	5.0165			
45		3.6131	40		3.9238	29		4.9939			
45	10	3.6040	40	10	3.9122	29	10	4.9716			
45	20	3.5949	40	20	3.9006	29	20	4.9495			
45	30	3.5859	40	30	3.8892	29	30	4.9277			
45	40	3.5770	40	40	3.8778	29	40	4.9061			
45	50	3.5681	40	50	3.8666	29	50	4.8848			
46		3.5593	41		3.8554	30		4.8637			
46	10	3.5506	41	10	3.8444	30	10	4.8428			
46	20	3.5419	41	20	3.8334	30	20	4.8222			
46	30	3.5333	41	30	3.8225	30	30	4.8018			
46	40	3.5247	41	40	3.8117	30	40	4.7816			
46	50	3.5163	41	50	3.8010	30	50	4.7617			
47		3.5078	42		3.7904	31		4.7420			

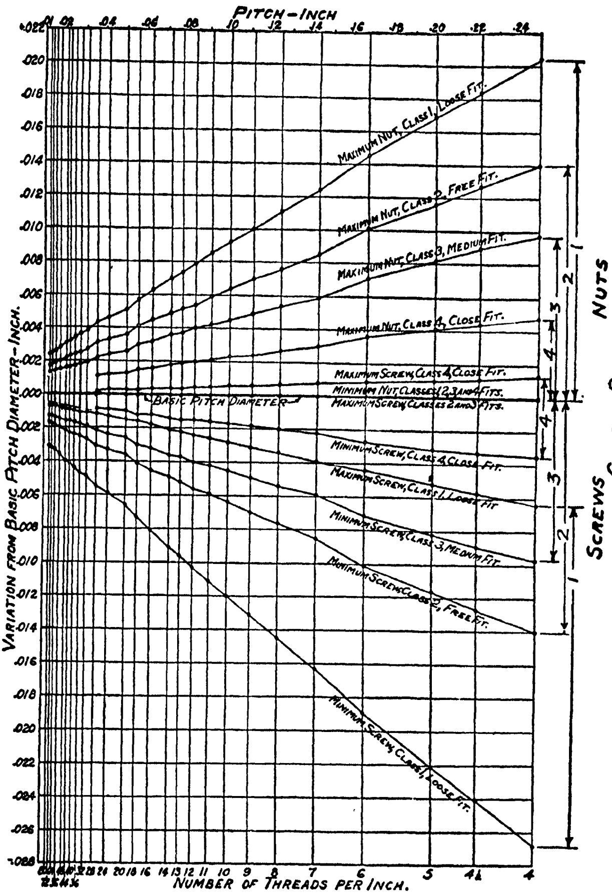


FIG. 9*a*.—Relation of Maximum and Minimum Pitch Diameters of Classes 1, 2, 3, and 4 Fits to Basic Pitch Diameters.

To Correct Pitch Diameter to Micrometer Reading

Table 36 will save many calculations. The decimal shown by the asterisk gives the amount to add to the pitch diameter to find the micrometer reading over the wires if the pitch diameter is correct. For a 1-inch, 8-pitch American thread, the pitch diameter is 0.91881 inch. With the best wire the table shows 0.108253 as the amount to add. The sum is 1.02711 as before. The other figures show the amounts to be added to the pitch diameter when wires of the other sizes designated are used.

For threads of other angles the following formulas are used:
Whitworth 55 degrees: $M = \text{P. D.} - 0.960491\ P + (3.1647\ G)$.
British Association 47½ inches:

$$M = \text{P. D.} - 1.13633\ P + (3.4829\ G).$$

Loewenherz 53 degrees 8 minutes: $M = \text{P. D.} - P + (3.23594\ G)$.
Acme 29 deg.: $M = \text{P. D.} - 1.93334\ P + (4.9938\ G)$.

FORMULAS FOR THREAD ANGLES OF 14½, 20, 22½, AND 25 DEGREES

The formulas for pitch diameter are as follows:

$$14\tfrac{1}{2} \text{ degree: } E = M + \frac{3.93032}{n} - 8.9270\ G.$$

$$20 \text{ degree: } E = M + \frac{2.83564}{n} - 6.7588\ G.$$

$$22\tfrac{1}{2} \text{ degree: } E = M + \frac{2.51367}{n} - 6.1258\ G.$$

$$25 \text{ degree: } E = M + \frac{2.25535}{n} - 5.6202\ G.$$

Values of necessary angles are:

Thread Angle	Half-Angle	sec *a*	cotan *a*	cosec *a*
14½	7¼	1.0080	7.86064	7.9270
20	10	1.0154	5.67128	5.7588
22½	11¼	1.0196	5.02734	5.1258
25	12½	1.0243	4.51071	4.6202

These formulas do not take into account the effect of helix angle which, in the case of multiple threads, is large. However, on worm threads, the matter of helix angle has been neglected so long that we have a standard that is not exactly correct but, nevertheless, is in universal use.

It is strongly advised that wires near the best size and of known accuracy be used, since any error in the size of the wire is multiplied by 5½ to 8 times in the formulas given.

TABLE 36.—CONVERTING AMERICAN PITCH DIAMETERS INTO MICROMETER READING BY THREE-WIRE THREAD MEASUREMENT

Formula: $3\,G - (P \times 0.866025)$ = amount to add to pitch diameter (see page 60).

THREADS PER INCH

Wire Sizes	3	3¼	3½	4	4½	5	5½	6	7	8
.1924498	*.288674	.310880	.329917							
.1776462		*.266469	.285506	.316432						
.1649572			*.247435	.278365	.302421					
.1443387				*.216509	.240566	.259811				
.1282998					*.192449	.211694	.227440			
.1154700						*.173205	.188951	.202073		
.1049727							*.157459	.170581	.191200	
.0962250								*.144338	.164957	.180421
.0824786									*.123718	.139182
.0641500										
.0721687										*.108253

Wire Sizes	9	10	11	11½	12	13	14	16	18
.0824786	.151210								
.0721687	.120281	.129903							
.0641500	*.096225	.105847	.113720						
.0577350		*.086602	.094475	.097898					
.0524863			*.078729	.082152	.085290				
.0502043				*.075306	.078444	.083995			
.0481125					*.072169	.077720	.082479		
.0444115						*.066617	.071376	.079108	
.0412393							*.061859	.069591	.075605
.0360841								*.054125	.060140
.0320741									*.048110

* Shows "Best Size" or Wire Touching on P. D.
Greenfield Tap & Die Corp.

TABLE 36.—CONVERTING AMERICAN PITCH DIAMETERS INTO MICROMETER READING BY THREE-WIRE THREAD MEASUREMENT.—*Continued*

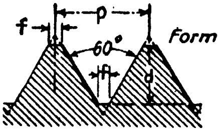
Formula: $3\,G - (P \times 0.866025)$ = amount to add to pitch diameter (see page 55).

	THREADS PER INCH									
Wire Sizes	19	20	22	24	26	27	28	30	32	34
.0360841	.062672									
.0320741	.050642	.052921								
.0303865	*.045579	.047858	.051795							
.0288675		*.043301	.047238	.050518						
.0262431			*.039365	.042645	.045421					
.0240553				*.036082	.038857	.040092				
.0222054					*.033308	.034541	.035687			
.0213833						*.032075	.033220	.035282		
.0206194							*.030929	.032991	.034795	
.0192448								*.028867	.030671	.032263
.0180421									*.027063	.028655
.0169804										*.025470

Wire Sizes	36	40	44	48	50	56	64	72	80
.0180421	.030070								
.0169804	.026885	.029290							
.0160370	*.024055	.026460	.028428						
.0144337		*.021650	.023619	.025259					
.0131214			*.019682	.021322	.022043				
.0120279				*.018041	.018763	.020619			
.0115470					*.017320	.019176	.021109		
.0103097						*.015464	.017397	.018901	
.0090210							*.013531	.015035	.016237
.0080184								*.012027	.013229
.0072168									*.010825

* Shows "Best Size" or Wire Touching on P. D.
Greenfield Tap & Die Corp.

TABLE 37.—DIMENSIONS OF METRIC THREADS



Formula
p = Pitch
d = Depth = p × 0.6495
f = Flat = p/8

Diameter of Screw mm.	Pitch mm.	Diameter at Root of Thread mm.	Width of Flat mm.
3	0.5	2.35	.06
4	0.75	3.03	.09
5	0.75	4.03	.09
6	1.0	4.70	.13
7	1.0	5.70	.13
8	1.0	6.70	.13
8	1.25	6.38	.16
9	1.0	7.70	.13
9	1.25	7.38	.16
10	1.5	8.05	.19
11	1.5	9.05	.19
12	1.5	10.05	.19
12	1.75	9.73	.22
14	2.0	11.40	.25
16	2.0	13.40	.25
18	2.5	14.75	.31
20	2.5	16.75	.31
22	2.5	18.75	.31
22	3.0	18.10	.38
24	3.0	20.10	.38
26	3.0	22.10	.38
27	3.0	23.10	.38
28	3.0	24.10	.38
30	3.5	25.45	.44
32	3.5	27.45	.44
33	3.5	28.45	.44
34	3.5	29.45	.44
36	4.0	30.80	.5
38	4.0	32.80	.5
39	4.0	33.80	.5
40	4.0	34.80	.5
42	4.5	36.15	.56
44	4.5	38.15	.56
45	4.5	39.15	.56
46	4.5	40.15	.56
48	5.0	41.51	.63
50	5.0	43.51	.63
52	5.0	45.51	.63
56	5.5	48.86	.69
60	5.5	52.86	.69
64	6.0	56.21	.75
68	6.0	60.21	.75
72	6.5	63.56	.81
76	6.5	67.56	.81
80	7.0	70.91	.88

TABLE 38.—THREE-WIRE MEASUREMENT OF AMERICAN THREAD (Dimensions in Inches)

No. Threads per Inch	$G = \frac{0.57735}{N}$ Diam. Best Wire	Best Wire Constant $H = \frac{0.86602}{N}$ Depth V Thread	$h = \frac{0.64951}{N}$ Depth American Thread	N = No. Threads per Inch	
				Min. Wire	Max. Wire
80	0.00722	0.01083	0.00812	0.00722	0.01155
72	0.00802	0.01203	0.00902	0.00802	0.01312
64	0.00902	0.01353	0.01014	0.00902	0.01443
56	0.01031	0.01546	0.01160	0.01031	0.01604
50	0.01155	0.01732	0.01299	0.01155	0.01804
48	0.01203	0.01804	0.01353	0.01155	0.02062
44	0.01312	0.01968	0.01476	0.01155	0.02221
40	0.01443	0.02165	0.01624	0.01312	0.02406
36	0.01604	0.02406	0.01804	0.01443	0.02624
32	0.01804	0.02706	0.02030	0.01604	0.02887
30	0.01924	0.02887	0.02161	0.01804	0.03039
28	0.02062	0.03093	0.02319	0.01924	0.03207
26	0.02221	0.03331	0.02498	0.02062	0.03608
24	0.02406	0.03608	0.02706	0.02221	0.03608
22	0.02624	0.03936	0.02952	0.02406	0.04124
20	0.02887	0.04330	0.03248	0.02624	0.04441
19	0.03039	0.04558	0.03418	0.02887	0.04811
18	0.03207	0.04811	0.03608	0.02887	0.05020
16	0.03608	0.05413	0.04060	0.03207	0.05774
14	0.04124	0.06186	0.04640	0.04124	0.06415
13	0.04441	0.06662	0.04996	0.04124	0.06415
12	0.04811	0.07217	0.05413	0.04441	0.07217
11½	0.05020	0.07531	0.05648	0.04811	0.07217
11	0.05249	0.07873	0.05904	0.05020	0.08248
10	0.05774	0.08660	0.06495	0.05249	0.09622
9	0.06415	0.09622	0.07218	0.05774	0.09622
8	0.07217	0.10825	0.08119	0.06415	0.10497
7	0.08248	0.12372	0.09279	0.07217	0.12830
6	0.09622	0.14434	0.10825	0.09622	0.14434
5½	0.10497	0.15746	0.11805	0.09622	0.14434
5	0.11547	0.17320	0.12990	0.10497	0.14434
4½	0.12830	0.19245	0.14434	0.11547	0.14434
4	0.14434	0.21651	0.16238	0.12830	

NOTE.—Sometimes taps have an outside diameter over basic, and the minimum wires given may not project above the tops of the thread.

With 60-degree threads H = both the depth of a V thread and also the best wire constant.

FORMULA FOR AMERICAN 60-DEGREE THREADS

Basic pitch diam. = Basic outside diam. − Depth American threads.
Measured pitch diam. = M + Depth V. Threads − $3G$.
If best wire is used,
Measured pitch diam. = M − best wire constant.

METRIC COARSE THREAD

DIAMETER, IN MILLIMETERS	PITCH, IN MILLIMETERS
3	0.50*
3.5	0.60
4	0.70
4.5	0.75
5.0	0.80
5.5	0.90
6	1.0
7	1.0
8	1.25
9	1.25
10	1.5

* France and Japan: 0.60.

The pitches of metric threads are generally given in millimeters, so that the number of threads per inch must be computed from these data and, of course, come out unevenly.

The pitches of metric coarse threads from 6 to 80 millimeters, inclusive, are the same in all countries that have adopted metric standard threads. For diameters below 6 millimeters, there are a few differences, as shown in the above table for the diameter of 3 millimeters.

FORMULA FOR 55-DEGREE THREADS

Basic pitch diam = Basic outside diam. − Depth of thread.

$$\text{Measured pitch diam.} = M + \frac{0.96049}{N} - 3{,}16568\,G.$$

If best size wire is used, then the

$$\text{Measured pitch diam.} = M - \text{best wire constant.}$$

CHECKING ANGLE OF THREAD

Using two sizes of wires, G_1 (large) and G_2 (small). If the angle is 55 degrees then

$$\frac{M_1 - M_2}{G_1 - G_2} = 3.1657.$$

For other angles the results shown below will be obtained:

Result	Angle	
	Degrees	Minutes
3.1840	54	30
3.1778	54	40
3.1717	54	50
3.1657	55	
3.1596	55	10
3.1536	55	20
3.1477	55	30

CHECKING ANGLE OF THREAD

Using two sizes of wires, G_1 (large) and G_2 (small).
If angle is 60 degrees then

$$\frac{M_1 - M_2}{G_1 - G_2} = 3.0000.$$

For other angles the following results will be obtained:

Result	Angle	
	Degrees	Minutes
3.0152	59	30
3.0101	59	40
3.0050	59	50
3.0000	60	
2.9950	60	10
2.9900	60	20
2.9850	60	30

TABLE 39.—WIRE SIZES AND CONSTANTS FOR 55-DEGREE THREADS

This includes British Standard Whitworth and British Standard Fine Threads

No. Threads per Inch	Diam. Best Wire = $G = \frac{0.563692}{N}$	Depth of V Thread 55 Degrees = $H = \frac{0.96049}{N}$	$h = \frac{0.6403}{N}$ = Depth of Whitworth Thread	Diam. Min. Wire	Diam. Max. Wire	Best Wire Constant $= \frac{0.82398}{N}$
40	0.01409	0.02401	0.01601	0.01409	0.02013	0.02060
36	0.01566	0.02668	0.01779	0.01409	0.02168	0.02289
32	0.01762	0.03002	0.02001	0.01762	0.02563	0.02577
28	0.02013	0.03430	0.02287	0.02013	0.02818	0.02943
26	0.02168	0.03694	0.02463	0.02013	0.03132	0.03169
24	0.02349	0.04002	0.02668	0.02349	0.03525	0.03433
22	0.02563	0.04366	0.02911	0.02349	0.03525	0.03745
20	0.02818	0.04802	0.03202	0.02563	0.04026	0.04120
18	0.03132	0.05336	0.03557	0.02818	0.04697	0.04577
16	0.03525	0.06003	0.04002	0.03525	0.05124	0.05155
14	0.04026	0.06861	0.04574	0.04026	0.05637	0.05886
12	0.04697	0.08004	0.05336	0.04697	0.07046	0.06866
11	0.05124	0.08732	0.05821	0.04697	0.07046	0.07491
10	0.05637	0.09605	0.06403	0.05124	0.08053	0.08240
9	0.06263	0.10672	0.07115	0.05637	0.09396	0.09155
8	0.07046	0.12006	0.08004	0.07046	0.09396	0.10300
7	0.08053	0.13721	0.09148	0.08053	0.11274	0.11771
6	0.09396	0.16008	0.10672	0.09396	0.14092	0.13733
5	0.11274	0.19210	0.12807	0.09396	0.14092	0.16480
4½	0.12526	0.21344	0.14230	0.11274	0.16105	0.18311
4	0.14092	0.24012	0.16008	0.14092	0.16105	0.20600
3½	0.16105	0.27443	0.18295	0.16105		0.23542

TABLE 40.—WIRE SIZES AND CONSTANTS FOR 60-DEGREE METRIC THREADS

Pitch in Millimeters, P	Approx. Threads per Inch, n	Diam. Best Wire, $G = \frac{0.57735}{n}$ in Inches	Depth of Sharp V Thread also Best Wire Constant, $H = \frac{0.86602}{n}$ in Inches	Depth of 60-degree Metric Thread, in Inches $h = \frac{0.64951}{n}$	For Min. Wire Use Best Wire of Pitch Given Below	For Max. Wire Use Best Wire of Pitch Given Below
0.24	105.8	0.00546	0.00818	0.00614	0.24	0.42
0.27	94.1	0.00614	0.00921	0.00690	0.24	0.45
0.30	84.7	0.00682	0.01023	0.00767	0.27	0.45
0.33	77.0	0.00750	0.01125	0.00831	0.30	0.45
0.36	70.6	0.00818	0.01227	0.00920	0.33	0.60
0.39	65.2	0.00886	0.01330	0.00981	0.33	0.60
0.42	60.5	0.00955	0.01432	0.01073	0.36	0.60
0.45	56.4	0.01023	0.01534	0.01150	0.42	0.75
0.50	50.8	0.01136	0.01705	0.01279	0.45	0.80
0.60	42.3	0.01364	0.02046	0.01534	0.60	1.00
0.75	33.9	0.01705	0.02557	0.01918	0.75	1.25
0.80	31.8	0.01818	0.02728	0.02046	0.75	1.25
0.90	28.2	0.02046	0.03069	0.02302	0.90	1.50
1.00	25.4	0.02273	0.03410	0.02556	1.00	1.75
1.25	20.3	0.02841	0.04262	0.03196	1.25	2.00
1.50	16.9	0.03410	0.05114	0.03836	1.50	2.50
1.75	14.5	0.03978	0.05967	0.04475	1.75	3.00
2.00	12.7	0.04546	0.06819	0.05112	1.75	3.50
2.50	10.2	0.05683	0.08524	0.06393	2.50	4.00
3.00	8.5	0.06819	0.10229	0.07672	3.00	5.00
3.50	7.3	0.07956	0.11933	0.08950	3.50	5.50
4.00	6.4	0.09092	0.13638	0.10221	3.50	7.00
4.50	5.6	0.10229	0.15343	0.11507	4.50	7.50
5.00	5.1	0.11365	0.17048	0.12786	4.50	7.50
5.50	4.6	0.12502	0.18752	0.14064	5.00	8.00
6.00	4.2	0.13638	0.20457	0.15343	5.50	8.00
6.50	3.9	0.14775	0.22162	0.16621	6.00	8.00
7.00	3.6	0.15911	0.23867	0.17900	6.50	8.00
7.50	3.4	0.17048	0.25572	0.19179	7.00	8.00
8.00	3.2	0.18184	0.27276	0.20457	7.00	

NOTE.—The thread depth given above corresponds to a ⅛ flat both at the top and bottom of the thread. Usually the flat at the bottom is made 1/16 the pitch to provide a greater clearance.

Formula same as American thread, including angle measurement.

Basic pitch diameter = Basic outside diameter − Depth of thread.

$$\text{Measured pitch diameter} = M - \left(3G - \frac{0.86602}{n}\right)$$

If best wire is used, then the

Measured pitch diameter = M − best wire constant.

TABLE 41.—BRITISH ASSOCIATION 47½-DEGREE THREADS BASIC SIZES, WIRE SIZES, AND CONSTANTS

Size	Pitch p, in Millimeters	Major Diam., D, in Millimeters	Pitch Diam., $D - h$, in Millimeters	Minor Diam., $D - 2h$, in Millimeters	Depth of Thread, $0.6p$, h, in Millimeters	Approx. No. of Threads per Inch, n	Major Diam., D, in Inches	Pitch Diam., E, in Inches	Diam. Best Wire, $0.54625p$, G, in Inches	Diam. Max. Wire, in Inches	Depth of V Thread, $1.13634p$, H, in Inches	Best Wire Constant, $3.4829\,G - 1.13634p$, W, in Inches
1	2	3	4	5	6	7	8	9	10	11	12	13
0	1.00	6.000	5.400	4.800	0.600	25.4	0.23622	0.21260	0.02151	0.02870	0.04474	0.03018
1	0.90	5.300	4.760	4.220	0.540	28.2	0.20866	0.18740	0.01936	0.02585	0.04026	0.02717
2	0.81	4.700	4.215	3.730	0.485	31.4	0.18504	0.16594	0.01742	0.02151	0.03624	0.02443
3	0.73	4.100	3.660	3.220	0.440	34.8	0.16142	0.14409	0.01570	0.01936	0.03266	0.02202
4	0.66	3.600	3.205	2.810	0.395	38.5	0.14173	0.12618	0.01419	0.01742	0.02953	0.01989
5	0.59	3.200	2.845	2.490	0.355	43.1	0.12598	0.11201	0.01269	0.01510	0.02640	0.01780
6	0.53	2.800	2.480	2.160	0.320	47.9	0.11024	0.09764	0.01140	0.01510	0.02371	0.01600
7	0.48	2.500	2.210	1.920	0.290	52.9	0.09842	0.08701	0.01032	0.01269	0.02147	0.01447
8	0.43	2.200	1.940	1.680	0.260	59.1	0.08661	0.07638	0.00925	0.01140	0.01924	0.01298
9	0.39	1.900	1.665	1.430	0.235	65.1	0.07480	0.06555	0.00839	0.01032	0.01745	0.01177
10	0.35	1.700	1.490	1.280	0.210	72.6	0.06693	0.05866	0.00753	0.00925	0.01566	0.01057
11	0.31	1.500	1.315	1.130	0.185	81.9	0.05906	0.05177	0.00667	0.00839	0.01387	0.00936
12	0.28	1.300	1.130	0.960	0.170	90.7	0.05118	0.04449	0.00602	0.00753	0.01253	0.00844
13	0.25	1.200	1.050	0.900	0.150	101.6	0.04724	0.04134	0.00538	0.00667	0.01118	0.00756
14	0.23	1.000	0.860	0.720	0.140	110.4	0.03937	0.03386	0.00495	0.00602	0.01029	0.00693
15	0.21	0.900	0.775	0.650	0.125	121.0	0.03543	0.03051	0.00452	0.00602	0.00939	0.00635

Formula:

$$r = \frac{2p}{11} = \text{radius at crest and root}$$

General formula using any size of wires

$$E = M - (3.4829G - 1.13634p)$$

Using best size wires

$$E = M - W$$

If wires differ by more than 0.00002 inch from best size given in the above table a new wire constant, W should be computed.

CHECKING ANGLE OF THREAD

Using two sizes of wires G_1 (large) and G_2 (small), then if the angle is 47½ degrees,

$$\frac{M_1 - M_2}{G_1 - G_2} = 3.4829.$$

For other angles the following results will be obtained:

Result	Angle	
	Degrees	Minutes
3.5078	47	
3.4995	47	10
3.4912	47	20
3.4829	47	30
3.4748	47	40
3.4666	47	50
3.4586	48	

Wire measurement tables by H. L. Van Keuren.

Optical Methods of Measuring Threads

There are several makes of apparatus for optical measurement, both in this country and abroad. One method makes direct observations of the magnified screw thread, while the other projects an image of the thread against a greatly magnified chart and compares the outlines in this way. With the apparatus set by a screw of correct pitch diameter, the projected shadow shows not only the thread form, but also whether the diameter is within the tolerance laid out on the chart. Some of these devices are very compact and allow of easy manipulation, so that screw threads can be inspected very rapidly. A chart from a Hartness comparator, Fig. 10, shows how the magnified shadow is compared with the greatly enlarged chart and very slight errors detected at a glance There are now several makes of instruments that compare outlines visually, as in this case. These instruments are also used for comparing outlines of gear teeth, milling cutters, and other contours.

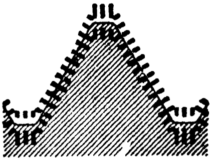


FIG. 10.—Checking Outline on Standard Chart

MEASURING THREAD DIAMETER WITH TWO AND THREE WIRES

D = outside diameter of thread.
D_1 = root diameter measured in thread groove.
n = number of threads per inch of length.
d = depth of thread.
p = distance from center to center of adjacent threads.
f = width of flat on American Standard thread.
a = diameter of wire used.
B = distance from apex of thread angle at root, to center of wire.
D_2 = diameter of cylinder touched by apexes of thread angles.

TABLE 42.—MEASURING AMERICAN STANDARD COARSE THREADS WITH MICROMETERS AND WIRES

D	n	D_1	D_2	a	B	$\left(\frac{\text{lead}}{2}\right)^2$	x	x_1	x_2
¼″	20	.1867	.1742	.04	.04	.000625	.2721	.2942	.2955
5/16″	18	.2419	.2283	.04	.04	.000771	.3304	.3483	.3495
⅜″	16	.2954	.2803	.04	.04	.000976	.3876	.4003	.4016
7/16″	14	.3465	.3292	.04	.04	.001274	.4433	.4492	.4507
½″	13	.4019	.3834	.06	.06	.001479	.5317	.5634	.5647
9/16″	12	.4561	.4362	.06	.06	.001735	.5893	.6162	.6177
⅝″	11	.5089	.4872	.06	.06	.002065	.6461	.6672	.6681
11/16″	11	.5712	.5497	.06	.06	.002065	.7086	.7297	.7312
¾″	10	.6221	.5984	.06	.06	.0025	.7643	.7784	.7801
13/16″	10	.6844	.6609	.06	.06	.0025	.8267	.8409	.8425
⅞″	9	.7327	.7066	0.10	0.10	.003086	.9408	1.0066	1.0083
15/16″	9	.7950	.7691	0.10	0.10	.003086	1.0033	1.0691	1.0706
1″	8	.8399	.8105	0.10	0.10	.003906	1.0553	1.1105	1.1124
1⅛″	7	.9421	.9085	0.10	0.10	.005102	1.1667	1.2085	1.2107
1¼″	7	1.0668	1.0335	0.10	0.10	.005102	1.2917	1.3335	1.3355
1⅜″	6	1.1614	1.1224	0.10	0.10	.006944	1.3987	1.4224	1.4250
1½″	6	1.2862	1.2474	0.10	0.10	.006944	1.5237	1.5474	1.5497
1⅝″	5½	1.3917	1.3494	0.15	0.15	.008263	1.7122	1.7994	1.8019
1¾″	5	1.4935	1.4469	0.15	0.15	.010	1.8234	1.8969	1.8997
1⅞″	5	1.6182	1.5719	0.15	0.15	.010	1.9484	2.0219	2.0245
2″	4½	1.7149	1.6632	0.15	0.15	.012343	2.0566	2.1132	2.1163
2⅛″	4½	1.8393	1.7882	0.15	0.15	.012343	2.1816	2.2382	2.2411
2¼″	4½	1.9641	1.9132	0.15	0.15	.012343	2.3066	2.3632	2.3667
2⅜″	4	2.0540	1.9961	0.15	0.15	.015625	2.4105	2.4461	2.4495
2½″	4	2.1787	2.1211	0.15	0.15	.015625	2.5355	2.5711	2.5742
2¾″	4	2.4284	2.3711	0.15	0.15	.015625	2.7855	2.8211	2.8240
3″	3½	2.6326	2.5670	0.20	0.20	.020392	3.0835	3.1670	3.1704
3¼″	3½	2.8823	2.8170	0.20	0.20	.020392	3.3335	3.4170	3.4200
3½″	3¼	3.1041	3.0337	0.20	0.20	.023654	3.5668	3.6337	3.6368
3¾″	3	3.3211	3.2448	0.20	0.20	.02775	3.7974	3.8448	3.8486
4″	3	3.5708	3.4948	0.20	0.20	.02775	4.0474	4.0948	4.0983
4¼″	2⅞″	3.8019	3.7228	0.20	0.20	.03024	4.2864	4.3228	4.3264
4½″	2¾″	4.0318	3.9489	0.20	0.20	.03305	4.5244	4.5500	4.5530
4¾″	2⅝″	4.2592	4.1728	0.20	0.20	.03625	4.7614	4.7728	4.7767
5″	2½″	4.4848	4.3938	0.20	0.20	.040	4.9970	4.9938	4.9980
5¼″	2½″	4.7346	4.6438	0.20	0.20	.040	5.2470	5.2438	5.2477
5½″	3⅜″	4.9574	4.8619	0.20	0.20	.04431	5.4810	5.4619	5.4661
5¾″	2⅜″	5.2072	5.1119	0.20	0.20	.04431	5.7310	5.7119	5.7160
6″	2¼″	5.4271	5.3264	0.20	0.20	.049373	5.9632	5.9264	5.9307

x = diameter from top of threads on one side of tap or bolt, to top of wire laid in thread groove on opposite side.
x_1 = diameter over 3 wires.
x_2 = diameter over 2 wires.

AMERICAN STANDARD COARSE THREAD

p = lead = $\frac{1}{n}$, for single threads.

$$d = p \times 0.6495 = \frac{0.6495}{n}.$$

$$D_1 = \sqrt{(D - 2d)^2 + \left(\frac{\text{lead}}{2}\right)^2}.$$

$$f = \frac{p}{8}.$$

a = from p, max.; to $p \times 0.505'$.

$$B = \frac{a}{2} \div \sin 30^\circ = a.$$

$$x = \frac{D}{2} + \frac{D_2}{2} + B + \frac{a}{2}.$$

$$x_1 = D_2 + 2B + a.$$

$$x_2 = \sqrt{(D_2 + 2B)^2 + \left(\frac{\text{lead}}{2}\right)^2} + a.$$

Thickness of Plating in Threads

Electroplating bolts and nuts, either for rust prevention or for appearance, adds something to the diameter and, consequently, affects the fits, both in the thread and in the body. Unless close fits are used, the thickness of the plating can usually be neglected, but for close fits it should be known and suitable allowance made. Where chromium is plated directly on steel, the thickness of the plate will probably not exceed 0.0001 inch. For a really high-class job, however, the steel should be first plated with copper, then with nickel, and, finally, with chromium. In such cases the total thickness of the three platings would be about 0.00075 inch.

In cadmium plating, which is used solely for rust prevention, the usual coating is 0.0002 inch. Neither chromium nor cadmium should show a tendency to build up in the threads but should give a uniform coating. The thickness of the coat is dependent on the time in the plating bath and, to some extent it is claimed, on the closeness of the pieces to each other.

Parkerizing is not supposed to increase the diameter of the piece treated but to secure the rustproofing qualities by its effect on the surface of the metal itself.

Measuring 29-Degree Threads

As Acme and worm threads are usually much coarser than 60-degree threads, the effect of the helix angle on wire measurement must be considered, as the less the thread angle, the more the interference. This is shown by the diagram in Fig. 11, where the helix angle raises the wire and gives a false reading unless correction is made.

The formula for calculating the helix correction, page 59, must always be considered when the correction is more than 0.00015 second. The reason for helix-angle correction can best be visualized if we consider taking a 29-degree threading tool and, on a lathe, cutting an annular groove in a piece of steel. If we lay a wire in this groove, the axis of the wire will be at right angles to the axis of the piece of steel and a line through the points of contact with the side walls is likewise parallel to the axis of the steel, as in Fig. 9.

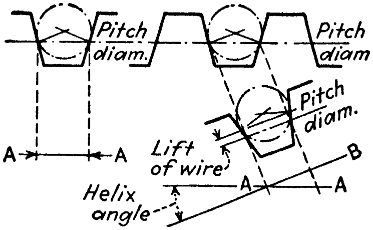


FIG. 11.—Effect of Helix Angle on Wire Measurement

TABLE 43.—CONVERTING THREE-WIRE MEASUREMENT TO 29-DEGREE THREAD PITCH DIAMETER

P. D. = measurement − constant

Measurement = P. D. + constant

Constant = (4.9939 W − 1.9333 P)

T.P.I.	Wire, *W*	Constant	Wire, *W*	Constant
1	0.516440*	0.64565		
1½	0.344293*	0.43058		
2	0.258220*	0.32282		
2½	0.206576*	0.25826		
3	0.1776462†	0.24268		
3½	0.1443375†	0.16842		
4	0.1443375	0.23746	0.1282998†	0.15736
4½	0.1154700†	0.14728	0.1282998	0.21134
5	0.1154700	0.18997	0.1049727†	0.13755
5½	0.0962250†	0.12901	0.1049727	0 17269
6	0.0962250	0.15832	0.0824786†	0 08967
7	0.0721687†	0.08422	0.0824786	0 13570
7½	0.0721687†	0.10262	0.0824786	0.15411
8	0.0721687	0.11872	0.0641500†	0.07868
9	0.0577350†	0.07350	0.0641500	0.10554
10	0.0577350	0.09498	0.0524863†	0.06877
12	0.0444115†	0.06067	0.0524863	0.10099

Use "best" wire where possible.
* Indicates "best size" wire.
† Indicates nearest to "best size" wire.

$$\text{Width of top of thread} = \frac{0.335}{\text{no. of threads per inch}}.$$

$$\text{Width of space at bottom} = \frac{0.310}{\text{no. of threads per inch}}.$$

$$\text{Clearance at bottom of thread} = \frac{\text{thickness at pitch line}}{10}.$$

$$\text{Width of space at top of thread} = \frac{0.665}{\text{no. of threads per inch}}.$$

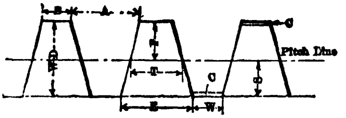
$$\text{Thickness at root of thread} = \frac{0.69}{\text{no. of threads per inch}}.$$

TABLE 44.—WIRE SIZES FOR MEASURING BROWN AND SHARPE 29-DEGREE WORM THREADS

Threads per Inch	Pitch	Diam. of Wire
½	2.	1.0298
4/7	1.750	0.9010
⅔	1.500	0.7723
⅘	1.250	0.6436
1	1.0	0.5149
1½	.6666	0.3432
2	.5	0.2574
2½	.4	0.2060
3	.3333	0.1716
3½	.2857	0.1471
4	.250	0.1287
4½	.2222	0.1144
5	.2	0.1030
6	.1666	0.0858
7	.1428	0.0735
8	.125	0.0643
9	.1111	0.0572
10	.10	0.0515
12	.0833	0.0429
16	.0625	0.0322
20	.050	0.0257

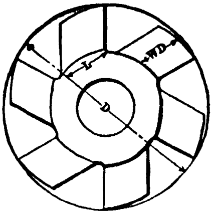
WORM WHEEL HOBS

Hobs are made larger in diameter than the worm with which they are used, by the amount of two clearances. The Brown and Sharpe method is to make the clearance one-tenth of the thickness of the tooth on the pitch line or 0.05 inch for a worm of one pitch. If the worm was 3 inches outside diameter, which would be a fair proportion for this pitch, the outside diameter of the hob would be $3 + (2 \times .05) = 3.1$ inches. The thread tool would be 0.335 inch wide at the point and would cut 0.6366 + 0.05 = 0.6866 deep, leaving the top of the thread 0.31 inch thick and the bottom 0.335 inch thick.



A = .69 × Pitch
B = .31 × Pitch
C = 1/16 of T
E = .665
F = .3683 × Pitch
S = .3183 × Pitch
T = .5 × Pitch
W = .335 × Pitch
WD = .6866 × Pitch

FIG. 12.—Section of Hob Thread



D = Diam. of Worm + 2C
L = WD + 1/8 inch
WD = .6866 × Pitch

FIG. 13.—End View of Hob

The body *L* should be made as near the proportions given as possible.

The diagram, Fig. 12, shows the shape and proportions of the thread of a worm hob, and Fig. 13 shows the proportions for the depth of tooth, the lead, and the outside diameter. In these diagrams:

A = width of space at top of tooth.
B = width of thread at top.
C = clearance or difference between the hob and worm.
D = diameter of hob.
E = width of tooth at bottom.
F = height above pitch line.
L = width of body or tooth at bottom.
S = depth below pitch line.
T = width at pitch line.
W = width of space at bottom.
WD = whole depth of tooth.

Brown and Sharpe allow clearance at the point of the tooth only for worm wheels, but at both point and bottom when hobbing spur gears.

MEASURING BROWN AND SHARPE 29-DEGREE WORM THREADS

The diameter of wire for Brown and Sharpe worm thread, Fig. 14, for each pitch that will rest in the thread groove on the thread angle and be flush with the tops of the finished threads is found as follows:

Radius of wire section (see table) = side opposite = side adjacent $\times \tan 37°45' = \frac{0.665\,P}{2} \times 0.77428 = 0.257447\,P$, and diameter of wire $= 0.5149\,P$.

Holding Work and Wires for Thread Measurement

Figure 15 shows a fixture for holding both work and wires while measuring threads by the three-wire system. It consists of a

TABLE 45.—BROWN AND SHARPE 29-DEGREE WORM THREAD PARTS

	P	D	F	W	T	A	C	S	B
Number of Threads Per Inch	Pitch of Single Thread	Depth of Thread	Width of Top of Thread	Width of Space at Bottom	Thickness of Thread at Pitch Line	Thread Above Pitch Line	Clearance at Bottom of Thread	Width of Space at Top	Thickness at Root of Thread
1	1.0	.6866	.3350	.3100	.5000	.3183	.05	.665	.69
1¼	.8	.5492	.2680	.2480	.4000	.2546	.04	.532	.552
1½	.6666	.4577	.2233	.2066	.3333	.2122	.0333	.4433	.4599
2	.5	.3433	.1675	.1550	.2500	.1592	.0250	.3325	.345
2½	.4	.2746	.1340	.1240	.2000	.1273	.0200	.2660	.276
3	.3333	.2289	.1117	.1033	.1666	.1061	.0166	.2216	.2299
3½	.2857	.1962	.0957	.0886	.1429	.0909	.0143	.1901	.2011
4	.250	.1716	.0838	.0775	.1250	.0796	.0125	.1637	.1725
4½	.2222	.1526	.0744	.0689	.1111	.0707	.0111	.1478	.1533
5	.2	.1373	.0670	.0620	.1000	.0637	.0100	.1330	.138
6	.1666	.1144	.0558	.0517	.0833	.0531	.0083	.1108	.115
7	.1428	.0981	.0479	.0443	.0714	.0455	.0071	.095	.0985
8	.125	.0858	.0419	.0388	.0625	.0398	.0062	.0818	.0862
9	.1111	.0763	.0372	.0344	.0555	.0354	.0055	.0739	.0766
10	.10	.0687	.0335	.0310	.0500	.0318	.005	.0665	.069
12	.0833	.0572	.0279	.0258	.0416	.0265	.0042	.0551	.0575
16	.0625	.0429	.0209	.0194	.0312	.0199	.0031	.0409	.0431
20	.050	.0343	.0167	.0155	.0250	.0159	.0025	.0332	.0345

V block, an adjustable clamp, and two adjustable brackets. One end of the work is clamped in the V block, and the measuring wires are suspended from the upper bracket, which has saw cuts for the suspension wires or strings to slip into. The hands are left free for manipulating the micrometer. The handles, or grip ends, of the measuring wires are drilled for the suspension wires or strings.

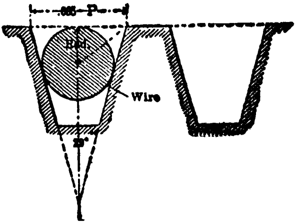


FIG. 14.—Measuring Brown and Sharpe Worm Threads

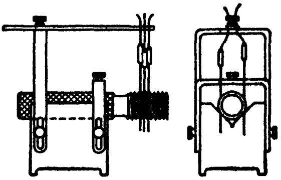


FIG. 15.—Holding Wires for Measurement

Worm threads formed by milling or grinding have convex instead of straight sides. The best wire should touch the threads at the pitch diameter.

MEASURING INTERNAL THREADS

To avoid the expense of threaded plug gages for larger size internal threads, this method (Fig. 16) was devised by William S. Rowell. Its greatest advantage over plug gages is that it can be used before work is to size. A plug cannot enter until work is to size or too large. A suitable size of internal micrometer is provided with ball contact points suitable for thread to be gaged. The slotted sleeve *S*—1 inch long—is to facilitate entering and removal from work.

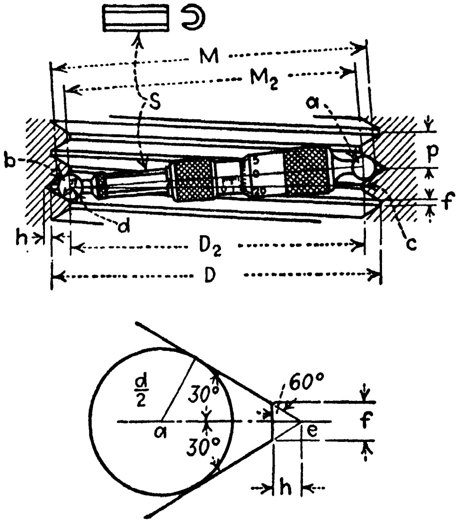


FIG. 16.—Measuring Internal Threads

In use, *M* is computed for the thread to be measured and the gage set to *M*, in order to read plus or minus. The thimble is turned to slightly minus. Sleeve *S* is removed and the rod telescoped in to enter the gage into the work. With *S* replaced, the thimble is turned out until balls contact thread grooves, as shown. Remove *S* and telescope the rod in. Remove the gage from the work, replace *S*, and note reading or measure with an outside micrometer. *M* may be computed by square root or trigonometry. Both methods are here given for a 4-*p* screw, 5 inches *D*, U.S. form.

Given

$$D = 5 \text{ inches.}$$
$$p = 0.25 \text{ inch.}$$
$$d = 0.15 \text{ inch.}$$

M is the measurement over the balls required.

Then:

$$f = \frac{p}{8} = 0.03125 \text{ inch.}$$

Since a 60-degree thread is specified:

$$\tan 60° = 1.7320 = h \div \frac{f}{2}$$

and

$$h = \frac{1.7320 \times 0.03125}{2} = 0.02706.$$

But $D_2 = D + 2h - 2d$ because the distance between the root of the thread and the center of the ball is the hypotenuse of a 30–60–90-degree triangle, of which the radius of the ball is the smallest side, that is, the hypotenuse ae equals twice the radius or d.

Then

$$\begin{aligned} D_2 &= 5 + 2 \times 0.02706 - 2 \times 0.15 \\ &= 5 + 0.05412 - 0.30 = 4.75412. \end{aligned}$$

Square-root method:

$$M = M_2 + d = \sqrt{D_2^2 + ac^2} + d.$$

But

$$ac = \frac{p}{2} = 0.125.$$

$$\begin{aligned} M &= \sqrt{(4.75412)^2 + (0.125)^2} + 0.15 \\ &= 4.7557 + 0.15 = 4.9057 \text{ inches.} \end{aligned}$$

Trigonometric method:

$$M = M_2 + d = \sec abc \times bc + d.$$

$$\tan abc = \frac{ac}{bc} = \frac{0.125}{4.75412} = 0.02629.$$

Then

$$\begin{aligned} abc &= 1°30'22'' \\ \sec abc &= 1.00035. \\ M &= 1.00035 \times 4.75412 + 0.15 \\ &= 4.7557 + 0.15 = 4.9057 \text{ inches.} \end{aligned}$$

CUTTING SCREW THREADS

Nearly all lathes are geared so that if gears having the same number of teeth are placed on both stud and lead screw, a thread the same pitch as the lead screw, will be cut. This is called being geared "even." If the lathe will not do this, then find what thread will be cut with even gears on both stud and lead screw and consider that as the pitch of lead screw. In speaking of the pitch of lead screw, it will mean the thread that will be cut with even gears.

In cutting the same thread with even gears, both the work and the lead screw are turning at the same rate. To cut a faster thread, the lead screw must turn faster than the work, so the larger gear goes on the stud and the smaller on the lead screw. To cut a slower thread (finer pitch or less lead), the larger gear goes on the screw and the smaller on the stud.

Calling the lead screw 6 to the inch, what gears shall we use to cut an 8 thread?

Multiply both the lead screw and the thread to be cut by some number (the same number for both) that will give two gears you have in the set. If the gears vary by 4 teeth, try 4, and you get 24 and 32 as the gears. If by 5, you get 30 and 40 as the gears. Then as 8 is slower than 6, the large gear goes on the lead screw and the small one on the stud.

To cut an 18 thread with a 5-pitch lead screw and gears varying by 5 teeth: 5 × 5 = 25 and 5 × 18 = 90. There may not be a 90 gear, but you can use a 2 to 1 compound gear and use a 45 gear instead. That is, put the 25 gear on the stud, use any 2 to 1 combination between this and the 45 gear on the screw.

The 25 gear must drive the large gear of the 2 to 1 combination and the small gear drive the 45-tooth gear, either directly or through an intermediate.

In cutting fractional threads the same rule holds good. To cut $11\frac{1}{2}$ threads with a 6-pitch lead screw and gears that change by 4 teeth, use $4 \times 6 = 24$ and $4 \times 11\frac{1}{2} = 46$, with the 24 gear on the stud and the 46 on the screw. With gears changing by 5 this is not so easy, as $5 \times 11\frac{1}{2} = 57\frac{1}{2}$, an impossible gear. Multiplying by 10 would give 60 and 115, not much better. Multiply by 6,

Having	To Find	Rule
A = True lead of screw and *B* = Thread to be cut	*C* = Gear for stud and *D* = Gear for screw	Multiply both *A* and *B* by any one number that will give gears in the set. Put gear *A* on stud and gear *B* on lead screw.
A = True lead of screw *B* = Thread to be cut *C* = Gear for stud	*D* = Gear for screw	Multiply *B* by *C* and divide by *A*.
A = True lead of screw *B* = Thread to be cut *D* = Gear for screw	*C* = Gear for stud	Multiply *A* by *D* and divide by *B*.
A = True lead of screw *C* = Gear for stud *D* = Gear for screw	*B* = Thread that will be cut	Multiply *A* by *D* and divide by *C*

and get $6 \times 6 = 36$ and $6 \times 11\frac{1}{2} = 69$, neither of which is in the set. Gears of 35 and 70 teeth will cut 12 threads per inch.

To find what thread any two gears will cut, multiply the pitch of lead screw and the gear which goes on it and divide this by the gear on the stud. Suppose we try 40 on the stud and 75 on the lead screw. Multiply 75 by $6 = 450$ and divide by 40 which gives $11\frac{1}{4}$ as the thread that will be cut. Try 45 and 80. $6 \times 80 = 480$; divided by $45 = 10\frac{2}{3}$, showing that the 40 and 75 are nearest and that to cut it exactly a special gear will have to be added to the set. In reality, the gears would not change by 5 teeth with a 6-pitch lead screw.

The ratio between the pitch of the lead screw and of the thread to be cut must be the same as the ratio between the gear on the stud and the gear on the lead screw.

Rules for screw-cutting may be summed up as follows, always remembering that the pitch of the lead screw is the thread that will be cut when gears having the same number of teeth are placed on both screw and stud.

As most engine lathes now have quick-change gear boxes, it is only necessary to learn the proper position of the gear-change lever, or handle, for each thread or feed. This can readily be done from the plate on the lathe itself.

Gears for Screw-Cutting

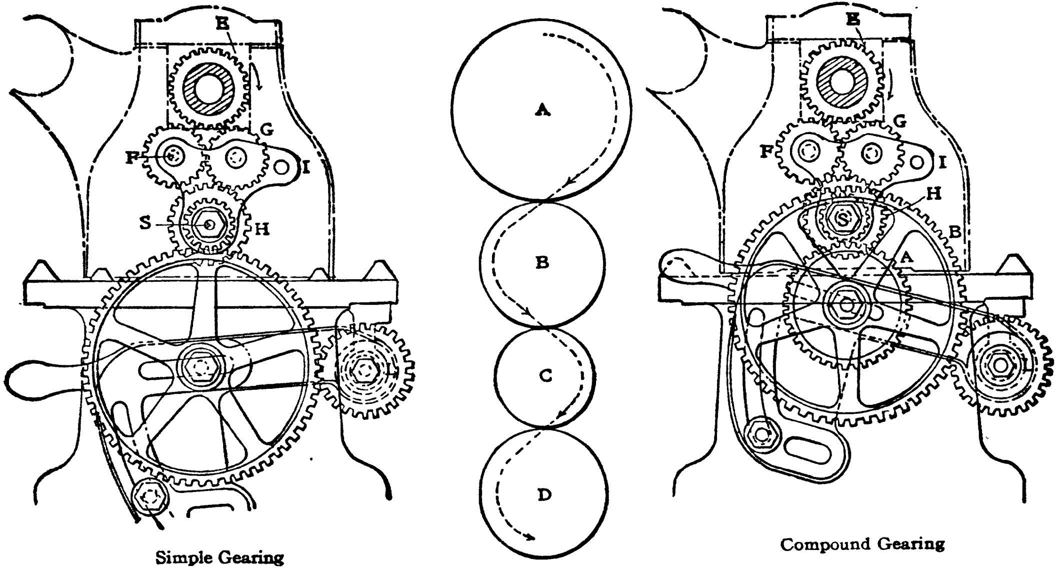
Gear trains for screw-cutting are usually arranged similarly to the illustration, Fig. 17. If the gear *E* on the lathe spindle has the same number of teeth as the gear *H* on the stud *S*, the lathe is geared even, that is, gears having the same teeth placed on both stud and lead screw will cut a thread like the lead screw. As shown, the gears are out of mesh because the tumbler gears *F* and *G* do not mesh with *E*; but moving the handle *I* down throws *F* into mesh with *E* so the drive is through *E*, *F*, *G*, *H*, *S* and intermediate to *L*, driving it so as to cut a left-hand screw if the lathe has a right-hand lead screw, as is usually the case. Raising handle *I* reverses the direction of the lead screw by driving through *E*, *G*, *H*, *S*, and *L*.

To follow the motion of a train of gears, take a stick (or your finger if they are *not* running) and trace the motion from the driver to the end as shown by the dotted lines in *A*, *B*, *C*, *D*.

When a lathe is compound geared, the stud gear drives an auxiliary gear as *A*, which multiplies or reduces the motion as the case may be. It will readily be seen that if the stud drives *A* and *B* drives *L*, the motion will be exactly doubled because *A* has one-half the number of teeth in *B*.

METRIC THREADS

Metric threads are measured in millimeters but often stated by the threads per centimeter. Any lathe with a pair of compound or "translating gears" with 50 and 127 teeth can cut metric threads, the large gear being driven from the stud. Then the gears for the number of threads per centimeter are figured the same as threads per inch, as on page 78.



Simple Gearing

Following Motion of a Gear Train

Compound Gearing

FIG. 17.—Lathe Gears for Screw-Cutting

The gears for millimeter threads can be easily found by a simple rule. Put the 127-tooth gear on the screw. The gear for stud is found by multiplying the number of threads per inch of the lead screw by the pitch to be cut in millimeters and by 5.

EXAMPLE.—To cut 2-millimeter pitch on a lathe with a lead screw having 4 threads per inch. The driving gear on the stud will be

Lead screw (4) × millimeters (2) × 5 = 40, the two gears being 40 on stud and 127 on screw.

EXAMPLE.—To cut a 10-millimeter thread with a 5-pitch lead screw.

Lead screw (5) × millimeters (10) × 5 = 250, the gears being 250 on stud and 127 on screw.

It will frequently be necessary to compound the gears to get the desired ratio with the gears in common use.

HELIX ANGLE OF SCREW THREADS

The helix angle of screw threads varies with both the diameter and the lead of the screw. The larger the diameter the less the helix angle for the same lead screw. The helix angle is used in grinding thread tools, and the pitch diameter should be considered instead of the outside.

The helix angles for standard threads are given in Table 1 on page 5. For other diameters and leads the following formula can be used.

HELIX-ANGLE FORMULA

P = single threads per inch. $\frac{1}{P}$ = lead = L.

D = pitch diameter of work in inches. $\pi = 3.1416 = \frac{C}{D}$.

C = pitch circumference of work in inches = πD.

$$\frac{L}{C} = \frac{\text{lead}}{\text{circumference of work}} = \frac{\frac{1}{P}}{\pi D} = \text{tangent of angle.}$$

Find angle in table of tangents

While the formula is worked out for single threads, it can be used for double or triple threads by considering the lead equal to the advance of the work in one revolution instead of $\frac{1}{P}$, as given in the formula.

It is customary in many shops to have several thread tools in stock to cut these various thread angles, each cutting within a certain range of angles. This table will be useful in determining the best range for each thread tool.

Figures 18 and 19 show side and front elevations of the thread tool and of the protractor as applied to obtain the proper angle of side clearance to cut a right-hand screw thread. The front edge of the thread tool is used to determine the angle of side clearance. Figure 20 shows a section taken along the line *ab*, Fig. 18. It will be noticed that line *ef* is shorter than *GH* to give clearance to the cutting edges of the thread tool, and also that *GR* is equal to *HR*, and

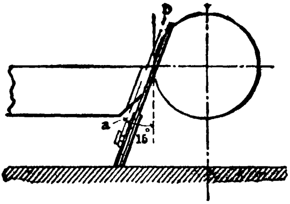


FIG. 18

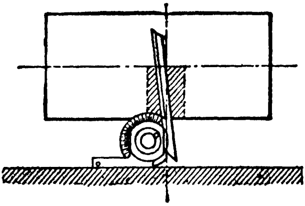


FIG. 19

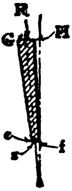


FIG. 20

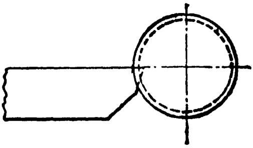


FIG. 21

The Use of the Protractor

TABLE 46.—MULTIPLE THREAD CUTTING

Threads per Inch	Thread Multiple	Carriage Movement	Lathe Screw Thd's per In.
1½—3/2	2	1″	Any
1½—3/2	3	Cannot be split this way.	
1½—3/2	4	½″	Any even thd.
1¾—7/4	2	2″	Any
1¾—7/4	3	1⅓″	6
1¾—7/4	4	1″	Any
2¼—9/4	2	2″	Any
2¼—9/4	3	Cannot be split this way.	
2¼—9/4	4	1″	Any
2½—5/2	2	1″	Any
2½—5/2	3	⅔″	3, 6, 9, 12.
2½—5/2	4	½″	Any even thd.
3 —3/1	2	½″	Any even thd.
3 —3/1	3	Cannot be split this way.	
3 —3/1	4	¼″	4

es is equal to *fs*. The thread tool must be set at the center as in Fig. 21 in order to cut a thread at the proper angle.

MULTIPLE THREAD CUTTING

Table 46 on page 82 will be found useful when cutting multiple threads. When one thread is cut, the feed nut may be opened (the spindle, of course, being stopped) and the carriage moved along by hand the distance given in the table; the nut is then closed on the screw and the next thread cut. This is a quick and sure method of starting the second, third, or fourth thread where the lead screw of the lathe is of the pitch given in the table.

TABLE 47.—DOUBLE DEPTH OF THREADS

Threads per in.	V Threads D D	U. S. St'd D D	Whit. St'd D D	Threads per in.	V Threads D D	U. S. St'd D D	Whit. St'd D D
2	.86650	.64950	.64000	28	.06185	.04639	.04571
2¼	.77022	.57733	.56888	30	.05773	.04330	.04266
2⅜	.72960	.54694	.53894	32	.05412	.04059	.04000
2½	.69320	.51960	.51200	34	.05097	.03820	.03764
2⅝	.66015	.49485	.48761	36	.04811	.03608	.03555
2¾	.63019	.47236	.46545	38	.04560	.03418	.03368
2⅞	.60278	.45182	.44521	40	.04330	.03247	.03200
3	.57733	.43300	.42666	42	.04126	.03093	.03047
3¼	.53323	.39966	.39384	44	.03936	.02952	.03136
3½	.49485	.37114	.36571	46	.03767	.02823	.02782
4	.43300	.32475	.32000	48	.03608	.02706	.02666
4½	.38488	.28869	.28444	50	.03464	.02598	.02560
5	.34660	.25980	.25600	52	.03332	.02498	.02461
5½	.31490	.23618	.23272	54	.03209	.02405	.02370
6	.28866	.21650	.21333	56	.03093	.02319	.02285
7	.24742	.18557	.18285	58	.02987	.02239	.02206
8	.21650	.16237	.16000	60	.02887	.02165	.02133
9	.19244	.14433	.14222	62	.02795	.02095	.02064
10	.17320	.12990	.12800	64	.02706	.02029	.02000
11	.15745	.11809	.11636	66	.02625	.01968	.01939
11½	.15069	.11295	.11121	68	.02548	.01910	.01882
12	.14433	.10825	.10666	70	.02475	.01855	.01828
13	.13323	.09992	.09846	72	.02407	.01804	.01782
14	.12357	.09278	.09142	74	.02341	.01752	.01729
15	.11555	.08660	.08533	76	.02280	.01714	.01673
16	.10825	.08118	.08000	78	02221	.01665	.01461
18	.09622	.07216	.07111	80	.02166	.01623	.01600
20	.08660	.06495	.06400	82	.02113	.01584	.01560
22	.07872	.05904	.05818	84	.02063	.01546	.01523
24	.07216	.05412	.05333	86	.02015	.01510	.01476
26	.0661	.04996	.04923	88	.01957	.01476	.01454
27	.06418	.04811	.04740	90	.01925	.01443	.01422

To determine whether multiple thread can be spaced by carriage movement, change the threads to be cut into a common fraction. Divide the numerator by the thread multiple. If it divides evenly, the thread cannot be spaced by moving the carriage. If it does not divide evenly, move the carriage the distance obtained by dividing the thread multiple into the denominator. The rule and examples given are by T. J. Lee.

The carriage can, of course, be moved 1 inch and the nut closed, no matter what the pitch of the lead screw may be (unless it is fractional), but in order to close the nut after moving ½ inch, the screw must have some even number of threads per inch.

As will be seen by referring to the table, a lead screw with any even number of threads per inch is used in a number of cases, while in several other instances the screw may be of any pitch—either odd or even. In certain cases, 4 and 8 per inch lead screws are specified; and in cutting triple threads a 6 per inch screw is usual.

This gives the depth to allow for a full thread in a nut or similar piece of work for threads for 2 to 90 per inch, regardless of the diameter. A special nut for a 2-inch bolt, 20 threads per inch, American Standard would have a hole 2.0 − 0.06495 = 1.93505 inches in diameter bored in it. It is generally better to allow for three-quarters depth than a full thread.

FACEPLATE FOR MULTIPLE THREAD CUTTING

Figure 22 shows a faceplate fixture used on various numbers of threads. On an ordinary driving plate is fitted a plate having, as

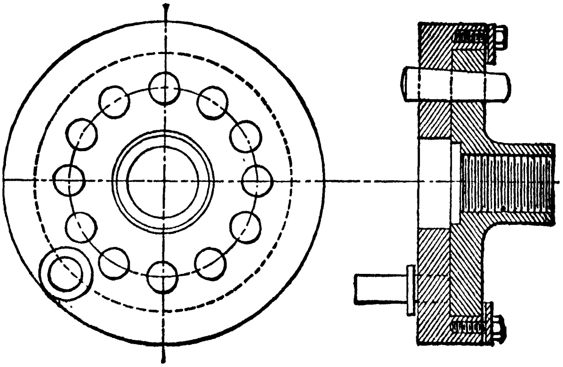


FIG. 22.—Faceplate for Multiple Thread Cutting

shown, twelve holes enabling one to get two, three, four or six leads if required. This ring carries the driving stud, and is clamped at the back of the plate by two bolts as an extra safeguard. All that is necessary in operation is to slack off the bolts, withdraw the index pin, move the plate the number of holes required, and retighten the bolts. It is used on different lathes, as occasion requires, by making the driving plates alike and drilling a hole for the index pin. It is found that the index pin works best when made taper, and a light tap is sufficient to loosen or fix it. Multiple threads can all be cut at the same time, using a properly located tool for each lead. The finishing cut is usually made with a single tool.

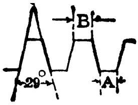
CUTTING DIAMETRAL PITCH WORMS IN THE LATHE

The accompanying table is to be used in cases where fractional worm-thread cutting is necessary for diametral pitch worm threads to mesh into diametral-pitch worm gears.

$$\text{Formula: } \left.\begin{matrix} 22 \times \text{lead screw} \\ 7 \times \text{diametral pitch} \end{matrix}\right\} = \text{ratio of wheels.}$$

The ratio 355:113 is more accurate than 22:7 but requires odd gears; a 71-tooth gear and a 5:1 compound give 355.

TABLE 48.—CHANGE GEARS FOR DIAMETRAL PITCH WORMS



Diametral Pitch	Single Depth	Width of Tool Point A	Width of Top of Thread B	Pitch of Lead Screw							
				2	3	4	5	6	7	8	10
2	1.078"	.487"	.526"	$\frac{22}{7}$	$\frac{33}{7}$	$\frac{44}{7}$	$\frac{55}{7}$	$\frac{66}{7}$	$\frac{77}{7}$	$\frac{88}{7}$	$\frac{110}{7}$
2½	.862"	.390"	.421"	$\frac{88}{35}$	$\frac{132}{35}$	$\frac{176}{35}$	$\frac{44}{7}$	$\frac{264}{35}$	$\frac{44}{5}$	$\frac{352}{35}$	$\frac{440}{35}$
3	.719"	.325"	.350"	$\frac{44}{21}$	$\frac{22}{7}$	$\frac{88}{21}$	$\frac{110}{21}$	$\frac{44}{7}$	$\frac{22}{3}$	$\frac{176}{21}$	$\frac{220}{21}$
3½	.616"	.278"	.300"	$\frac{88}{49}$	$\frac{132}{49}$	$\frac{176}{49}$	$\frac{220}{49}$	$\frac{264}{49}$	$\frac{44}{7}$	$\frac{352}{49}$	$\frac{440}{49}$
4	.540"	.243"	.263"	$\frac{11}{7}$	$\frac{33}{14}$	$\frac{22}{7}$	$\frac{55}{14}$	$\frac{33}{7}$	$\frac{11}{2}$	$\frac{44}{7}$	$\frac{55}{7}$
5	.431"	.195"	.210"	$\frac{44}{35}$	$\frac{66}{35}$	$\frac{88}{35}$	$\frac{22}{7}$	$\frac{132}{35}$	$\frac{22}{5}$	$\frac{176}{35}$	$\frac{44}{7}$
6	.360"	.162"	.175"	$\frac{22}{21}$	$\frac{11}{7}$	$\frac{44}{21}$	$\frac{55}{21}$	$\frac{22}{7}$	$\frac{11}{3}$	$\frac{88}{21}$	$\frac{110}{21}$
7	.308"	.139"	.150"	$\frac{44}{49}$	$\frac{66}{49}$	$\frac{88}{49}$	$\frac{110}{49}$	$\frac{132}{49}$	$\frac{22}{7}$	$\frac{176}{49}$	$\frac{220}{49}$
8	.270"	.122"	.131"	$\frac{11}{14}$	$\frac{33}{28}$	$\frac{11}{7}$	$\frac{55}{28}$	$\frac{33}{14}$	$\frac{11}{4}$	$\frac{22}{7}$	$\frac{55}{14}$
9	.240"	.108"	.117"	$\frac{44}{63}$	$\frac{22}{21}$	$\frac{88}{63}$	$\frac{110}{63}$	$\frac{44}{21}$	$\frac{22}{9}$	$\frac{176}{63}$	$\frac{220}{63}$
10	.216"	.097"	.105"	$\frac{22}{35}$	$\frac{33}{35}$	$\frac{44}{35}$	$\frac{11}{7}$	$\frac{66}{35}$	$\frac{11}{5}$	$\frac{88}{35}$	$\frac{22}{7}$
11	.196"	.088"	.096"	$\frac{4}{7}$	$\frac{6}{7}$	$\frac{8}{7}$	$\frac{10}{7}$	$\frac{12}{7}$	$\frac{14}{7}$	$\frac{16}{7}$	$\frac{20}{7}$
12	.180"	.081"	.088"	$\frac{11}{21}$	$\frac{11}{14}$	$\frac{22}{21}$	$\frac{55}{42}$	$\frac{11}{7}$	$\frac{11}{6}$	$\frac{44}{21}$	$\frac{55}{21}$
14	.154"	.069"	.075"	$\frac{22}{49}$	$\frac{33}{49}$	$\frac{44}{49}$	$\frac{55}{49}$	$\frac{66}{49}$	$\frac{11}{7}$	$\frac{88}{49}$	$\frac{110}{49}$
16	.135"	.061"	.066"	$\frac{11}{28}$	$\frac{33}{56}$	$\frac{22}{28}$	$\frac{55}{56}$	$\frac{33}{28}$	$\frac{77}{56}$	$\frac{11}{7}$	$\frac{55}{28}$
18	.120"	.054"	.058"	$\frac{22}{63}$	$\frac{11}{21}$	$\frac{44}{63}$	$\frac{55}{63}$	$\frac{22}{21}$	$\frac{11}{9}$	$\frac{88}{63}$	$\frac{110}{63}$
20	.108"	.048"	.053"	$\frac{11}{35}$	$\frac{33}{70}$	$\frac{22}{35}$	$\frac{11}{14}$	$\frac{33}{35}$	$\frac{77}{70}$	$\frac{44}{35}$	$\frac{11}{7}$
24	.090"	.040"	.044"	$\frac{11}{42}$	$\frac{11}{28}$	$\frac{11}{21}$	$\frac{55}{84}$	$\frac{22}{28}$	$\frac{77}{84}$	$\frac{22}{21}$	$\frac{55}{42}$
28	.077"	.034"	.038"	$\frac{11}{49}$	$\frac{33}{98}$	$\frac{22}{49}$	$\frac{55}{98}$	$\frac{33}{49}$	$\frac{11}{14}$	$\frac{44}{49}$	$\frac{55}{49}$
32	.067"	.030"	.033"	$\frac{11}{56}$	$\frac{33}{112}$	$\frac{11}{28}$	$\frac{55}{112}$	$\frac{33}{56}$	$\frac{11}{16}$	$\frac{11}{14}$	$\frac{55}{56}$
40	.054"	.024"	.026"	$\frac{11}{70}$	$\frac{33}{140}$	$\frac{11}{35}$	$\frac{11}{28}$	$\frac{33}{70}$	$\frac{11}{20}$	$\frac{22}{35}$	$\frac{11}{14}$
48	.045"	.020"	.022"	$\frac{11}{84}$	$\frac{11}{56}$	$\frac{11}{42}$	$\frac{55}{168}$	$\frac{11}{28}$	$\frac{11}{24}$	$\frac{11}{21}$	$\frac{55}{84}$

In the first column is found the diametral pitch to be cut. In the second column is found the corresponding single depth of the worm thread. Under the third column is found the width of the tool at the point, the tool being the regular 29-degree included angle. In the fourth column is found the width at the top of the worm thread.

The next heading in the chart is "Pitch of lead screw," and here are found different pitches of lead screws 2 to 10.

EXAMPLE.—Suppose it is desired to cut a worm thread of 4 diametral pitch on a single-geared lathe having a 6-pitch lead screw. Opposite 4 in the first column find the single depth of worm thread, or 0.540 inch; and continuing in the same direction from left to right, under the next column find the width of the worm-thread tool at the point or end, which is 0.243 inch, and so on to the next column, where is found the width of the worm thread at the top, which is 0.263 inch. Say there is a 6-pitch lead screw on the lathe. Then follow right on in the same direction to the column headed 6, which shows the gear ratio to be $\frac{33}{7}$. Of course, there is no 7 gear on the lathe, so simply bring the fraction $\frac{33}{7}$ to higher denominations, say $\frac{33}{7} \times \frac{3}{3} = \frac{99}{21}$, that is, put the 99 gear on the spindle or stud, and the 21 gear on the screw. Then use a gear of any convenient size to act as an intermediate gear, and thus connect the gear on the spindle with the gear on the screw. Taking the fraction $\frac{33}{7}$ and multiplying the numerator and denominator by 4 would give $\frac{132}{28}$ as the two gears to be used. It will be seen that this last fraction simply changes the number of teeth in the gears but does not change the value of the fraction; thus, there is the same ratio of gears.

LEAD GEARS FOR DIAMETRAL PITCH WORMS

C. A. Johnson, Perkins Gear & Machine Company, presents another method. Practically all spur, helical, and bevel gears are now made to the diametral pitch system because of the simplicity of its calculations. Worm gearing has been made to the circular-pitch system because of the ease of gearing a machine to produce worms with leads which are simple fractions. This practice is now being gradually superseded by the diametral pitch system. The one disadvantage, that of calculating change gears, is obviated by Table 49, page 88, giving the four gears necessary to produce the correct lead on a worm of any diametral pitch from 1 to 60 and any number of threads from 1 to 8.

The diametral pitch is found at the left-hand side of the table, and in the column under the desired number of threads is found the change gears which will produce the correct lead. The table is divided horizontally into three sections. Gearing for the coarse pitches (1 to 4) is calculated for a machine with a 3-inch constant, that is, a machine which *will produce a lead of* 3 *inches with equal gears*. The medium pitches (5 to 20) are calculated for a machine with a 1-inch constant, and the fine pitches (22 to 60) are calculated for a machine with a $\frac{1}{2}$-inch constant. In every case the largest gears to produce the desired ratio are given. For some ratios these may be factored if smaller gears are desired. All of the gear ratios in the table are the closest to the desired ratio which may be obtained using gears with tooth numbers from 24 to 100. The required gears are as follows:

3-inch machine—35 gears in all
  1 each—24, 25, 28, 30, 34, 35, 36, 42, 43, 44, 47, 48, 51, 55, 60, 61, 62, 68, 70, 72, 75, 77, 84, 86, 88, 89, 95, 98, 99.
  2 each—25, 50, 100.

1-inch machine—59 gears in all
  1 each—25, 27, 28, 29, 31, 32, 33, 34, 35, 40, 41, 42, 43, 44, 45, 47 48, 51, 52, 55, 56, 58, 59, 61, 62, 63, 64, 65, 66, 68, 70, 72, 73, 76, 77, 78, 80, 81, 82, 84, 85, 86, 87, 88, 89, 90, 91, 93 94, 95, 96, 98, 99.
  2 each—50, 75, 100.

½-inch machine—62 gears in all
  1 each—26, 27, 28, 29, 31, 32, 33, 34, 35, 41, 42, 43, 44, 45, 46, 47, 48, 51, 52, 55, 56, 57, 58, 59, 61, 62, 63, 64, 65, 68, 69, 70 73, 76, 77, 78, 79, 80, 81, 82, 84, 85, 86, 87, 88, 89, 90, 91, 92, 94, 95, 96, 98, 99.
  2 each—50, 66, 75, 100.

It may be necessary to cut a worm on a machine of different constant than that for which the change gears are tabulated. The procedure for finding the correct set of gears is as follows:

Suppose that a 3 D.P. gear is to be cut on a 2-constant machine. The gears for a 3-constant machine are of 34, 75, 77, and 100 teeth. To maintain the same lead on the worm, however, it will be necessary to increase the ratio of the change gears in the ratio of 3 to 2. Thus, $\frac{3 \times 34 \times 77}{2 \times 75 \times 100}$, which by factoring becomes $\frac{68 \times 77}{100 \times 100}$.

TABLE 49.—LEAD GEARS FOR DIAMETRAL PITCH WORMS

Diametral Pitch	Number of Starts or Leads																																Machine Constant
	1				2				3				4				5				6				7				8				
	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	
1	68	50	77	100	68	50	77	50	51	25	77	50	68	25	77	50	85	25	77	50	51	25	77	25	85	24	89	43	68	25	77	25	3
1¼	68	84	89	86	68	84	89	43	85	70	89	43	68	42	89	43	68	25	77	50	85	35	89	43	85	30	89	43	100	95	77	43	
1½	68	75	77	100	68	75	77	50	68	50	77	50	68	25	77	75	85	25	77	75	68	25	77	50	85	36	89	43	98	47	75	28	
1¾	68	100	88	100	68	100	88	50	68	50	99	75	68	50	88	50	85	50	88	50	68	25	99	75	68	25	77	50	68	25	88	50	
2	68	100	77	100	68	100	77	50	51	50	77	50	68	50	77	50	85	50	77	50	51	25	77	50	85	48	89	43	68	25	77	50	
2½	34	84	89	86	68	84	89	86	62	55	68	61	68	84	89	43	68	50	77	50	85	70	89	43	85	60	89	43	68	42	89	43	
3	34	75	77	100	68	75	77	100	68	50	77	100	68	75	77	50	85	75	77	50	68	50	77	50	85	72	89	43	68	75	77	25	
3½	68	100	44	100	68	100	88	100	68	100	99	75	68	100	88	50	85	100	88	50	51	50	88	50	68	50	77	50	68	50	88	50	
4	34	100	77	100	68	100	77	100	51	50	77	100	68	100	77	50	85	100	77	50	51	50	77	50	85	48	89	86	68	50	77	50	
5	62	55	34	61	62	55	68	61	93	55	68	61	68	56	89	43	51	25	77	50	51	28	89	43	85	40	89	43	85	35	89	43	1
6	68	100	77	100	68	100	77	50	51	50	77	50	68	50	77	50	85	50	77	50	51	25	77	50	85	48	89	43	68	25	77	50	
7	68	100	66	100	68	100	99	75	51	50	99	75	68	50	99	75	85	50	99	75	68	50	99	50	51	25	77	50	68	25	66	50	
8	51	100	77	100	51	100	77	50	66	58	88	85	51	50	77	50	51	40	77	50	66	29	88	85	77	29	88	85	51	25	77	50	
9	34	75	77	100	68	75	77	100	68	50	77	100	68	75	77	50	85	75	77	50	68	50	77	50	85	72	89	43	68	25	77	75	
10	31	55	34	61	62	55	34	61	62	55	51	61	62	55	68	61	51	50	77	50	93	55	68	61	85	80	89	43	85	70	89	43	
11	51	100	56	100	68	100	84	100	68	100	63	50	68	100	84	50	51	50	98	70	68	50	63	50	51	50	98	50	68	50	84	50	
12	34	100	77	100	68	100	77	100	51	50	77	100	68	100	77	50	85	50	77	100	51	50	77	50	85	58	89	86	68	50	77	50	
13	32	73	43	78	41	65	59	77	48	73	86	78	85	91	89	86	51	50	77	65	96	73	86	78	85	52	89	86	85	91	89	43	
14	51	100	44	100	68	100	66	100	51	50	66	100	68	100	99	75	85	100	99	75	51	50	99	75	51	50	77	50	66	50	68	50	
15	42	94	45	96	34	85	89	86	62	55	34	61	68	84	89	86	68	50	77	100	62	55	68	81	68	96	89	43	68	42	89	86	
16	33	85	44	87	51	100	77	100	66	87	66	85	51	50	77	100	51	50	77	80	99	87	88	85	77	58	88	85	51	50	77	50	

TABLE 49.—LEAD GEARS FOR DIAMETRAL PITCH WORMS.—*Continued*

Diametral Pitch	Number of Starts or Leads																																Machine Constant
	1				2				3				4				5				6				7				8				
	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	
17	42	100	44	100	56	100	66	100	84	100	66	100	84	100	88	100	84	100	99	90	84	100	99	75	98	100	99	75	84	75	99	75	1
18	31	99	34	61	34	75	77	100	68	100	77	100	68	75	77	100	51	50	77	90	68	50	77	100	85	72	89	86	68	74	77	50	
19	32	70	34	94	41	77	59	95	43	73	80	95	63	76	75	94	82	77	59	76	86	73	80	95	85	76	89	86	63	76	75	47	
20	27	64	35	94	31	55	34	61	55	95	70	86	62	55	34	61	51	50	77	100	62	55	51	61	85	80	89	86	62	55	68	61	
22	51	100	56	100	68	100	84	100	68	100	63	50	68	100	84	50	51	50	98	70	68	50	63	50	51	50	98	50	68	50	84	50	½
24	34	100	77	100	68	100	77	100	51	50	77	100	68	100	77	50	85	50	77	100	51	50	77	50	85	48	89	86	68	50	77	50	
26	32	73	43	78	41	65	59	77	48	73	86	78	85	91	89	86	51	50	77	65	96	73	86	78	85	52	89	86	85	91	89	43	
28	51	100	44	100	68	100	66	100	51	50	66	100	68	100	99	75	85	100	99	75	51	50	99	75	51	50	77	50	66	50	68	50	
30	42	94	45	96	34	84	89	86	62	55	34	61	68	84	89	86	68	50	77	100	62	55	68	81	68	96	89	43	68	42	89	86	
32	33	85	44	87	51	100	77	100	66	87	66	85	51	50	77	100	51	50	77	80	99	87	88	85	77	58	88	85	51	50	77	50	
34	42	100	44	100	56	100	66	100	84	100	66	100	84	100	88	100	84	100	99	90	84	100	99	75	98	100	99	75	84	75	99	75	
36	31	99	34	61	34	75	77	100	68	100	77	100	68	75	77	100	51	50	77	90	68	50	77	100	85	72	89	86	68	75	77	50	
38	32	70	34	94	41	77	59	95	43	73	80	95	63	76	75	94	82	77	59	76	86	73	80	95	85	76	89	86	63	76	75	47	
40	27	64	35	94	31	55	34	61	55	95	70	86	62	55	34	61	51	50	77	100	62	55	51	61	85	80	89	86	62	55	68	61	
42	34	100	44	100	68	100	44	100	68	100	66	100	68	100	88	100	85	100	88	100	68	100	99	75	68	100	77	50	68	100	88	50	
44	34	100	42	100	51	100	56	100	68	100	63	100	68	100	84	100	85	100	84	100	68	100	63	50	51	50	98	100	68	100	84	50	
46	26	69	29	80	32	69	43	73	64	92	43	73	63	92	75	94	82	92	59	77	64	92	86	73	85	92	89	86	63	46	75	94	
48	26	79	35	88	34	100	77	100	51	100	77	100	68	100	77	100	85	100	77	100	51	50	77	100	85	96	89	86	68	100	77	50	
50	27	94	42	96	28	57	44	86	56	95	55	86	56	57	44	86	62	55	34	61	56	57	66	86	85	100	89	86	56	57	88	86	
56	34	100	33	100	51	100	44	100	51	100	66	100	68	100	66	100	85	100	66	100	51	50	66	100	51	50	77	100	68	100	99	75	
60	27	94	35	96	42	94	45	96	31	55	34	61	34	84	89	86	68	100	77	100	62	55	34	61	70	82	79	92	68	84	89	86	

SECTION II

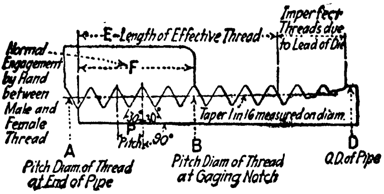
PIPE AND PIPE THREADS

AMERICAN STANDARD PIPE THREADS

The American or Briggs Pipe Thread Standard was formulated by Robert Briggs prior to 1882. It has been modified to conform to pitch diameter instead of outside diameter, and the tables now given have been approved by the leading technical associations, through the American Engineering Standard Committee. Although the tables and illustrations appear quite different than in previous editions, the essential dimensions are very similar.

DIAGRAM SHOWING NOTATION OF AMERICAN STANDARD TAPER PIPE THREAD (see Table 1)

$A = D - (0.05D + 1.1)P.$
$B = A + 0.0625F.$
$E = (0.80D + 6.8)P.$
Depth of thread $= 0.80P.$


Normal Engagement by Hand between Male and Female Thread
E-Length of Effective Thread
Imperfect Threads due to Lead of Die
F
30°
30°
P
Pitch
90°
Taper 1 in 16 measured on diam.
A
Pitch Diam. of Thread at End of Pipe
B
Pitch Diam of Thread at Gaging Notch
D
O.D. of Pipe

$A = D - (0.05D + 1.1)P$ $B = A + 0.0625F$ $E = P(0.8D + 6.8)$ Depth of Thrd. $= 0.8P$

FIG. 1.—Standard Notations (see Table 1)

The taper is 1 to 16 inches, or $\frac{3}{4}$ inch per foot. The thread angle is 60 degrees measured from the axis of the pipe. Mr. Briggs originally advocated rounding the threads, but they are slightly flattened to 0.033 of the pitch instead. The formula now gives the *effective* length of thread, that includes two threads slightly imperfect, while the old formula gave the length of *perfect* threads (see Fig. 1).

Diameter of Taper Thread.—The pitch diameters of the taper thread are determined by formulas based on the outside diameter of pipe and the pitch of thread. These are as follows:

$$A = D - (0.050D + 1.1)P. \quad B = A + 0.0625F$$

where A = pitch diameter of thread at end of pipe.
B = pitch diameter of thread at gaging notch.
D = outside diameter of pipe.
F = normal engagement by hand between external and internal threads.
P = pitch of thread.

Length of Thread.—The length of the taper external or male thread is determined by a formula based on the outside diameter of the pipe and the pitch of the thread. This is as follows:

$$E = (0.80D + 6.8)P$$

where E = length of effective thread.
D = outside diameter of pipe.
P = pitch of thread.

Depth of thread = $0.80\,P$.

For engagement of threads, see F in Table 1.

Gages and Methods of Gaging

Gages to maintain interchangeability of product properly should consist of master gages, reference gages used for checking working gages (see Figs. 2, 3, and 4), and working gages used for checking the product. The dimensions and use of these gages are described below.

Master Gage.—The master gage is a taper-threaded plug gage. This should be accompanied by two taper-threaded ring gages (known as checks) to afford ready comparisons. The plug gage is made to the dimensions given in Table 1, and shown in the diagram and in Figs. 2, 3, and 4. It includes the gaging notch, or the difference between E and F in Table 1.

One ring (check) has a thickness equal to dimension F, is the same diameter at the small end as the small end of the plug gage, and is flush with the plug gage at the small end and at the gaging notch when screwed on tight by hand (see Fig. 2). This check will be fitted to its master.

The other ring (check) has a thickness equal to dimension E, but is threaded for a distance equal to E minus F. It is the same diameter at the large end as the large end of the plug gage. The distance equal to F is counterbored and unthreaded (see Fig. 3). This check will also be fitted to its master.

The roots of the threads are cut to a sharp V, or may be undercut beyond the sharp V to facilitate making the thread (see Fig. 4). The crests are truncated[1] an amount equal to $0.1P$, as illustrated in Fig. 4.

Master gages and their checks are primarily for the use of gage and thread-tool manufacturers, and for very accurate reference in checking gages.

Reference Gage.—The reference gage consists of one taper-threaded plug gage and two taper-threaded ring gages. The plug gage is made to the dimensions given in Table 1 and shown in Figs. 2, 3, and 4. It includes the gaging notch.

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[1] The object of truncating the crests on gages (truncation $0.1P$) is to insure that, when gaging a commercial thread cut with a slightly dull tool, the gage bears on the sides of the thread instead of on the roots.

One ring gage has a thickness equal to dimension *F*, is the same diameter at the small end as the small end of the plug gage, and is flush with the plug gage at the small end and at the gaging notch when screwed on tight by hand (see Fig. 2).

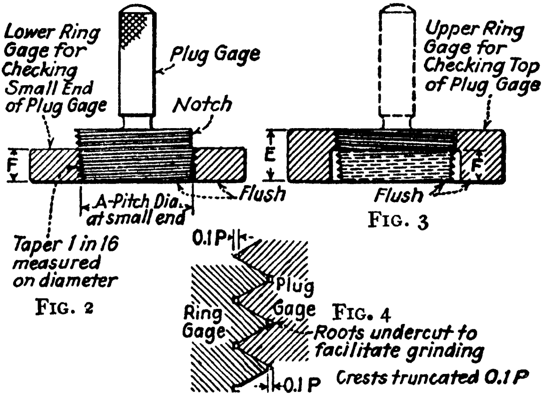

Lower Ring Gage for Checking Small End of Plug Gage
Plug Gage
Notch
F
A-Pitch Dia. at small end
Flush
Taper 1 in 16 measured on diameter
Upper Ring Gage for Checking Top of Plug Gage
E
F
Flush
0.1 P
Plug Gage
Ring Gage
Roots undercut to facilitate grinding
0.1 P
Crests truncated 0.1 P

FIG. 2 FIG. 3 FIG. 4

Reference Gages for Checking Working Gages

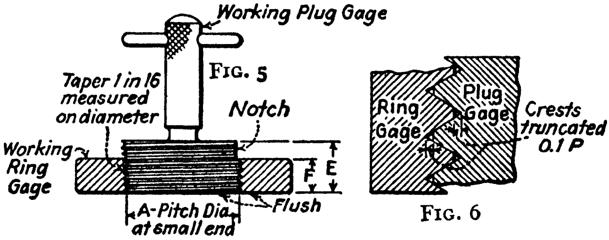


FIG. 5 FIG. 6

Working Gages for Checking Product

FIGS. 2 to 6

The other ring gage has a thickness equal to dimension *E* but is threaded for a distance equal to *E* minus *F*. It is the same diameter at the large end as the large end of the plug gage. The distance equal to *F* is counterbored and unthreaded (see Fig. 3).

Working Gage.—The working gage consists of one taper-threaded plug gage and one taper-threaded ring gage. The plug gage is made to the dimensions given in Table 1, and shown in Figs. 5 and 6. It includes the gaging notch.

The ring gage has a thickness equal to dimension *F* and is the same diameter at the small end as the small end of the plug gage (see Fig. 5).

The crests are truncated an amount equal to 0.1P. The roots are cut to a sharp V, or may be undercut beyond the sharp V to facilitate making the thread (see Fig. 6).

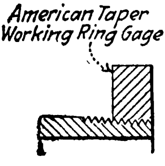


FIG. 7

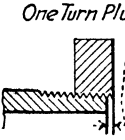


FIG. 8

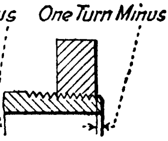


FIG. 9

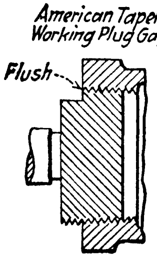


FIG. 10

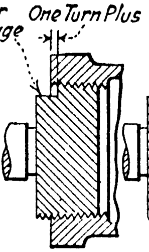


FIG. 11

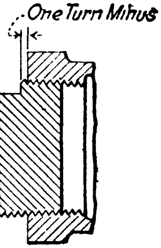


FIG. 12

Gaging Taper External Threads.—In gaging external or male threads, the ring gage, Fig. 5, should screw tight by hand on the pipe or male thread until the small end of the gage is flush with the end of the thread (see Fig. 7).

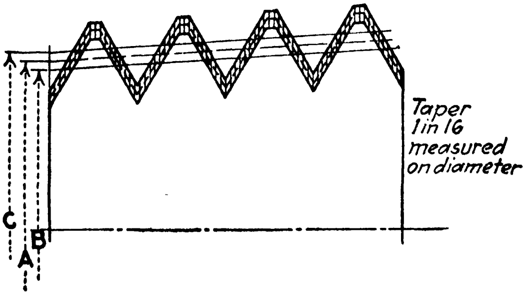


FIG. 13.—Diagram of Pipe Gage Thread

Gaging Taper Internal Threads.—In gaging internal or female threads, the plug gage, Fig. 5, should screw tight by hand into the fitting or coupling until the notch is flush with the face. When the thread is chamfered, the notch should be flush with the bottom of the chamfer.

This method of gaging is used either for taper internal (female) threads or for straight threaded couplings which screw together with taper external (male) threads (see Figs. 10 and 13).

GAGE AND WORKING TOLERANCES

Gage Tolerances.—In the manufacture of gages, variations from basic dimensions are unavoidable. Furthermore, gages will wear in use. In order to fix the maximum allowable variations of gages, tolerances have been established.

Master-Gage Tolerances.—Master gages should be made within the narrowest possible limits of error, and checks should be fitted to their masters. Each master gage should, in addition, be accompanied by a record of all measurements and a statement of the decimal part of a turn that it varies, plus or minus, from the basic dimensions.

Table 2, column 1, is used when checking gages by measurement.

No point on the thread surface of the gage should be outside of the zone of tolerance indicated by the shaded portion of the illustration.

The dotted line indicates the outline of a perfect gage made exactly to the basic dimensions.

A = basic pitch diameter at small end of gage.
B = minimum pitch diameter at small end of gage.
C = maximum pitch diameter at small end of gage.
$B = A -$ Column 1 from Table 2 for reference gages.
$C = A +$ Column 1 from Table 2 for reference gages.

Column 2 gives the equivalent of column 1, expressed in terms of distance parallel to the axis, and represents the maximum distance that a reference ring gage of perfect thickness or a reference plug gage of perfect length from small end to gaging notch may vary from being flush at the gaging notch or at the small end, when referred to basic dimensions. It is equal to 16 times column 1, owing to the basic taper of 1 in 16, measured on the diameter. This column is used when checking reference gages by comparison with a master gage. The necessary allowance must be made, of course, for the error in the master.

Column 3 gives the equivalent of column 2, expressed in terms of the decimal part of a turn from the basic dimensions. This column is also used when checking reference gages by comparison with a master gage. In this operation the necessary allowance must be made for the error in the master.

A tolerance of plus or minus 0.0002 inch (0.005 millimeter) is allowed on the distance between the gaging notch and the small end of the reference plug gage, or on the thickness of the reference ring gage. It is possible for reference plug and ring gages which come within all of the above tolerances to vary from being flush with each other at the small end, or at the gaging notch, when screwed together tightly by hand. The maximum variation which might occur, expressed in terms of distance, is given in column 4, and gages which come within these limits should be checked by measurement before being rejected. Working gage tolerance is twice the tolerance allowed in the reference gages.

Manufacturing Tolerances.—The maximum allowable variation in the commercial product is one turn plus or one turn minus from the gaging notch when using working gages (see Figs. 8, 9, 11, and 12). This is equivalent to a maximum allowable variation of one and one-half turns from the basic dimensions, owing to the allowance of one-half turn on working gages.

Figure 13 is a diagram of a pipe-thread gage.

STRAIGHT THREAD AND ITS USES

While the taper external and internal threads are recommended for threaded joints for every service, there are certain uses for a straight pipe thread. Straight threaded female wrought-iron or wrought-steel couplings of the weight known as "standard" may be used with taper-threaded pipe for ordinary pressures, as they are sufficiently ductile to adjust themselves to the taper male thread when properly screwed together. (For dimensions, see Table 4.) For high pressures, however, only taper-threaded pipe and fittings should be used.

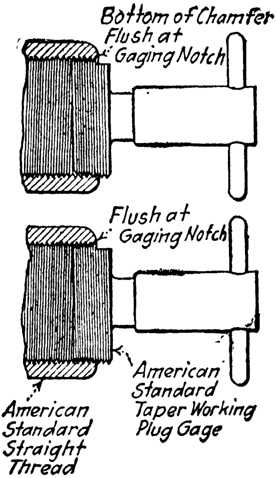

Bottom of Chamfer Flush at Gaging Notch
Flush at Gaging Notch
American Standard Taper Working Plug Gage
American Standard Straight Thread

FIG. 14

Straight male threads are recognized only for special applications, such as long screws and tank nipples.

In gaging, the American taper working plug gage is used, allowing the same tolerance from the notch as for a taper thread (see Fig. 14). The straight thread on the pipe enters the coupling freely by hand, the joint being made by a packing material between the locknut and the coupling.

TABLE 1.—DIMENSIONS OF AMERICAN STANDARD TAPER PIPE THREAD. SEE FIG. 1

Nominal Size		A		B		E		F		D		Depth of Thread		Number of Threads	
Inches	Millimeters	Inches	Millimeters	Inches	Millimeters	Inches	Millimeters	Inches	Millimeters	Inches	Millimeters	Inches	Millimeters	Per Inch	Per 254 Millimeters
⅛	3	0.36351	9.233	0.37476	9.519	0.2638	6.700	0.180	4.572	0.405	10.287	0.02963	0.753	27	270
¼	6	0.47739	12.126	0.48989	12.443	0.4018	10.206	0.200	5.080	0.540	13.716	0.04444	1.129	18	180
⅜	10	0.61201	15.545	0.62701	15.926	0.4078	10.358	0.240	6.096	0.675	17.145	0.04444	1.129	18	180
½	13	0.75843	19.264	0.77843	19.772	0.5337	13.556	0.320	8.128	0.840	21.336	0.05714	1.451	14	140
¾	19	0.96768	24.579	0.98886	25.117	0.5457	13.861	0.339	8.611	1.050	26.670	0.05714	1.451	14	140
1	25	1.21363	30.826	1.23863	31.461	0.6828	17.343	0.400	10.160	1.315	33.401	0.06956	1.767	11½	115
1¼	32	1.55713	39.551	1.58338	40.218	0.7068	17.953	0.420	10.668	1.660	42.164	0.06956	1.767	11½	115
1½	38	1.79609	45.621	1.82234	46.287	0.7235	18.377	0.420	10.668	1.900	48.260	0.06956	1.767	11½	115
2	50	2.26902	57.633	2.29627	58.325	0.7565	19.215	0.436	11.074	2.375	60.235	0.06956	1.767	11½	115
2½	64	2.71953	69.076	2.76216	70.159	1.1375	28.892	0.682	17.323	2.875	72.025	0.10000	2.540	8	80
3	76	3.34063	84.852	3.38850	86.068	1.2000	30.480	0.766	19.456	3.500	88.900	0.10000	2.540	8	80
3½	90	3.83750	97.473	3.88881	98.776	1.2500	31.750	0.821	20.853	4.000	101.600	0.10000	2.540	8	80
4	100	4.33438	110.093	4.38713	111.433	1.3000	33.020	0.844	21.438	4.500	114.300	0.10000	2.540	8	80
4½	113	4.83125	122.714	4.88594	124.103	1.3500	34.290	0.875	22.225	5.000	127.000	0.10000	2.540	8	80
5	125	5.39073	136.925	5.44929	138.412	1.4063	35.720	0.937	23.800	5.563	141.300	0.10000	2.540	8	80
6	150	6.44609	163.731	6.50597	165.252	1.5125	38.417	0.958	24.333	6.625	168.275	0.10000	2.540	8	80
7	175	7.43984	188.972	7.50234	190.560	1.6125	40.957	1.000	25.400	7.625	193.675	0.10000	2.540	8	80
8	200	8.43359	214.214	8.50003	215.901	1.7125	43.497	1.063	27.000	8.625	219.075	0.10000	2.540	8	80
9	225	9.42734	239.455	9.49797	241.249	1.8125	46.037	1.130	28.702	9.625	244.475	0.10000	2.540	8	80
10	250	10.54531	267.851	10.62094	269.772	1.9250	48.895	1.210	30.734	10.750	273.050	0.10000	2.540	8	80
11	275	11.53906	293.093	11.61938	295.133	2.0250	51.435	1.285	32.639	11.750	298.450	0.10000	2.540	8	80
12	300	12.53281	318.334	12.61781	320.493	2.1250	53.975	1.360	34.544	12.750	323.851	0.10000	2.540	8	80
14 O.D.	350	13.77500	349.886	13.87262	352.365	2.250	57.150	1.562	39.675	14.000	355.601	0.10000	2.540	8	80
15 O.D.	375	14.76875	375.127	14.87419	377.805	2.350	59.690	1.687	42.850	15.000	381.001	0.10000	2.540	8	80
16 O.D.	400	15.76250	400.368	15.87575	403.245	2.450	62.230	1.812	46.025	16.000	406.401	0.10000	2.540	8	80
17 O.D.	425	16.75625	425.609	16.87500	428.626	2.550	64.770	1.900	48.260	17.000	431.801	0.10000	2.540	8	80
18 O.D.	450	17.75000	450.851	17.87500	454.026	2.650	67.310	2.000	50.800	18.000	457.201	0.10000	2.540	8	80
20 O.D.	500	19.73750	501.333	19.87031	504.707	2.850	72.390	2.125	53.975	20.000	508.001	0.10000	2.540	8	80
22 O.D.	550	21.72500	551.816	21.86562	555.388	3.050	77.470	2.250	57.150	22.000	558.801	0.10000	2.540	8	80
24 O.D.	600	23.71250	602.299	23.86094	606.069	3.250	82.550	2.375	60.325	24.000	609.601	0.10000	2.540	8	80
26 O.D.	650	25.70000	652.781	25.85625	656.750	3.450	87.630	2.500	63.500	26.000	660.401	0.10000	2.540	8	80
28 O.D.	700	27.68750	703.264	27.85156	707.431	3.650	92.710	2.625	66.675	28.000	711.201	0.10000	2.540	8	80
30 O.D.	750	29.67500	753.746	29.84687	758.112	3.850	97.790	2.750	69.850	30.000	762.001	0.10000	2.540	8	80

TABLE 2.—TOLERANCES FOR REFERENCE GAGES

Nominal Size		1 Total Cumulative Tolerance on Diameter (see Fig. 16)		2 Equivalent Longitudinal Variation (16 × column 1)		3 Equivalent Angular Variation Expressed as Decimal Part of One Turn	4 Variations in Distance*	
Inches	Millimeters	Inches	Millimeters	Inches	Millimeters		Inches	Millimeters
⅛	3	0.00020	0.0050	0.0032	0.081	0.086	0.0068	0.173
¼	6	0.00022	0.0056	0.0035	0.089	0 063	0.0074	0.188
⅜	10	0.00024	0.0061	0.0038	0.097	0.068	0.0080	0.203
½	13	0.00026	0.0066	0.0042	0.107	0.059	0.0088	0.224
¾	19	0.00028	0.0071	0.0045	0.114	0.063	0.0094	0.239
1	25	0.00030	0.0076	0.0048	0.122	0.055	0.0100	0.254
1¼	32	0.00032	0.0081	0.0051	0.130	0.059	0.0106	0.269
1½	38	0.00034	0.0086	0.0054	0.137	0.062	0.0112	0.284
2	50	0.00036	0.0091	0.0058	0.147	0.067	0.0120	0.305
2½	64	0.00038	0.0097	0.0061	0.155	0.050	0 0126	0.320
3	76	0.00038	0.0097	0.0061	0.155	0.050	0 0126	0.320
3½	90	0.00041	0.0104	0.0066	0.168	0.053	0.0136	0.345
4	100	0.00043	0.0109	0.0069	0.175	0.055	0.0142	0.361
4½	113	0.00045	0.0114	0.0072	0.183	0.058	0.0148	0.376
5	125	0.00047	0.0119	0.0075	0.191	0.060	0.0154	0.391
6	150	0.00051	0.0130	0 0082	0.208	0.065	0.0168	0.427
7	175	0.00055	0.0140	0.0088	0.224	0.070	0.0180	0.457
8	200	0.00069	0.0150	0.0094	0.239	0.075	0.0192	0.488
9	225	0.00063	0.0160	0.0101	0.257	0.080	0.0206	0.523
10	250	0.00066	0.0168	0.0106	0.269	0.085	0.0216	0.549
12	300	0.00074	0.0188	0.0118	0.300	0.095	0.0240	0.610
14	350	0.00082	0.0208	0.0131	0.333	0.105	0.0266	0.676
16	400	0.00090	0.0229	0.0144	0.366	0.115	0.0292	0.742
18	450	0.00098	0.0249	0.0157	0.399	0.125	0.0318	0.808
20	500	0.00106	0.0269	0.0170	0.432	0.135	0.0344	0.874
22	550	0.00113	0.0287	0.0181	0.460	0.145	0.0366	0.930
24	600	0.00121	0.0307	0.0194	0.493	0.155	0.0392	0.996
26	650	0.00129	0.0328	0.0206	0.523	0.165	0 0416	1.057
28	700	0.00137	0.0348	0.0219	0.556	0.175	0.0442	1.123
30	750	0.00144	0.0366	0.0230	0.584	0.185	0.0464	1.179

* Maximum amount it is possible for plug and ring gages to vary from being flush at small end or at gaging notch when screwed together tight by hand. (2 times column 2 + 0.0004 inch.)

TABLE 3.—DIMENSION OF STANDARD PIPE

Nominal Size		Inside Diameter		External Diameter		Nominal Thickness		Transverse Areas				Length of Pipe per Sq. Ft. of External Surface	Length of Pipe per Sq. M. of External Surface	Nominal Weight per Ft. Threaded and Coupled	Nominal Weight per M. Threaded and Coupled
								Internal		Metal					
Inches	Millimeters	Inches	Millimeters	Inches	Millimeters	Inches	Millimeters	Sq. Inches	Sq. Millimeters	Sq. Inches	Sq. Millimeters	Feet	Meters	Pounds	Kilograms
1/8	3	0.269	6.833	0.405	10.287	0.068	1.727	0.057	36.77	0.072	46.45	9.431	30.94	0.245	0.364
1/4	6	0.364	9.246	0.540	13.716	0.088	2.235	0.104	67.10	0.125	80.64	7.073	23.20	0.425	0.632
3/8	10	0.493	12.522	0.675	17.145	0.091	2.311	0.191	123.23	0.167	107.74	5.658	18.56	0.568	0.845
1/2	13	0.622	15.799	0.840	21.336	0.109	2.769	0.304	196.13	0.250	161.29	4.547	14.91	0.852	1.268
3/4	19	0.824	20.930	1.050	26.670	0.113	2.870	0.533	343.87	0.333	214.84	3.637	11.93	1.134	1.687
1	25	1.049	26.645	1.315	33.401	0.133	3.378	0.864	557.42	0.494	318.71	2.904	9.53	1.684	2.506
1 1/4	32	1.380	35.052	1.660	42.164	0.140	3.556	1.495	964.52	0.669	431.61	2.301	7.55	2.281	3.394
1 1/2	38	1.610	40.894	1.900	48.260	0.145	3.683	2.036	1313.55	0.799	515.48	2.010	6.59	2.731	4.064
2	50	2.067	52.502	2.375	60.325	0.154	3.912	3.355	2164.52	1.075	693.55	1.608	5.27	3.678	5.473
2 1/2	64	2.469	62.713	2.875	73.025	0.203	5.156	4.788	3089.04	1.704	1099.36	1.328	4.36	5.819	8.660
3	76	3.068	77.927	3.500	88.900	0.216	5.486	7.393	4769.69	2.228	1437.42	1.091	3.58	7.616	11.334
3 1/2	90	3.548	90.119	4.000	101.600	0.226	5.740	9.886	6378.08	2.680	1729.03	0.954	3.13	9.202	13.694
4	100	4.026	102.261	4.500	114.300	0.237	6.020	12.730	8212.92	3.174	2047.74	0.848	2.78	10.889	16.204
4 1/2	113	4.506	114.453	5.000	127.000	0.247	6.274	15.947	10288.41	3.688	2379.35	0.763	2.50	12.642	18.813

5	125	5.047	128.194	5.563	141.300	0.258	6.553	20.006	12907.12	4.300	2774.20	0.686	2.25	14.810	22.040
6	150	6.065	154.051	6.625	168.275	0.280	7.112	28.891	18639.39	5.581	3600.65	0.576	1.89	19.185	28.550
7	175	7.023	178.385	7.625	193.675	0.301	7.645	38.738	24992.31	6.926	4468.39	0.500	1.64	23.769	35.372
8	200	8.071	205.004	8.625	219.075	0.277	7.036	51.161	33007.16	7.265	4687.10	0.442	1.45	25.000	37.204
8	200	7.981	202.718	8.625	219.075	0.322	8.179	50.027	32275.55	8.399	5418.72	0.442	1.45	28.809	42.872
9	225	8.941	227.102	9.625	244.475	0.342	8.687	62.786	40507.17	9.974	6434.85	0.396	1.30	34.188	50.877
10	250	10.192	258.877	10.750	273.050	0.279	7.087	81.585	52635.58	9.178	5921.30	0.355	1.16	32.000	47.621
10	250	10.136	257.455	10.750	273.050	0.307	7.798	80.691	52058.81	10.072	6498.08	0.355	1.16	35.000	52.086
10	250	10.020	254.508	10.750	273.050	0.365	9.271	78.855	50874.29	11.908	7682.59	0.355	1.16	41.132	61.211
11	275	11.000	279.400	11.750	298.450	0.375	9.525	95.033	61311.73	13.401	8645.82	0.325	1.07	46.247	68.823
12	300	12.090	307.087	12.750	323.851	0.330	8.382	114.800	74064.66	12.876	8307.11	0.299	0.98	45.000	66.967
12	300	12.000	304.801	12.750	323.851	0.375	9.525	113.097	72965.95	14.579	9405.82	0.299	0.98	50.706	75.459

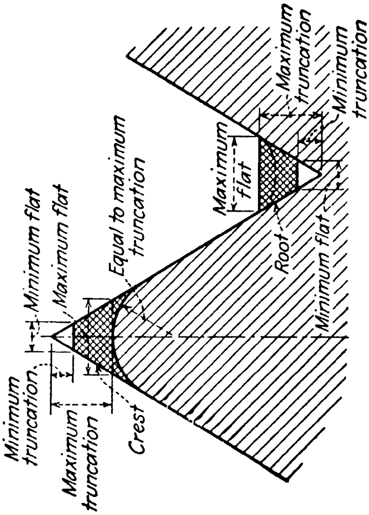


FIG. 14*a*.—Limits on Crest and Root Truncation of Product. The Values of the Maximun and Minimun Truncations and the Equivalent Width of Flats Are Given in the New Standard.

Further investigation by committees of the American Standards Association found it desirable to flatten or truncate the thread at the bottom as well as at the top, as mentioned on page 93. The original standard set a truncation of 0.033 × pitch for all threads. This has now been increased to a maximum of 0.096 × pitch for twenty-seven threads per inch and 0.073 × pitch for eleven and one-half threads per inch. Complete data requiring twelve new tables, can be secured from the American Standards Association, New York Central Office Building, New York.

Figure 14*a* shows the truncations and how they are designated.

Table 4.—Dimensions of American Standard Straight Pipe Thread

Nominal Size		B		Depth of Thread		Number of Threads	
Inches	Milli-meters	Inches	Milli-meters	Inches	Milli-meters	Per Inch	Per 254 Milli-meters
⅛	3	0.37476	9.519	0.02963	0.753	27	270
¼	6	0.48989	12.443	0.04444	1.129	18	180
⅜	10	0.62701	15.926	0.04444	1.129	18	180
½	13	0.77843	19.772	0.05714	1.451	14	140
¾	19	0.98886	25.117	0.05714	1.451	14	140
1	25	1.23863	31.461	0.06956	1.767	11½	115
1¼	32	1.58338	40.218	0.06956	1.767	11½	115
1½	38	1.82234	46.287	0.06956	1.767	11½	115
2	50	2.29627	58.325	0.06956	1.767	11½	115
2½	64	2.76216	70.159	0.10000	2.540	8	80
3	76	3.38850	86.068	0.10000	2.540	8	80
3½	90	3.88881	98.776	0.10000	2.540	8	80
4	100	4.38713	111.433	0.10000	2.540	8	80
4½	113	4.88594	124.103	0.10000	2.540	8	80
5	125	5.44929	138.412	0.10000	2.540	8	80
6	150	6.50597	165.252	0.10000	2.540	8	80
7	175	7.50234	190.560	0.10000	2.540	8	80
8	200	8.50003	215.901	0.10000	2.540	8	80
9	225	9.49797	241.249	0.10000	2.540	8	80
10	250	10.62094	269.772	0.10000	2.540	8	80
11	275	11.61938	295.133	0.10000	2.540	8	80
12	300	12.61781	320.493	0.10000	2.540	8	80
14 O.D.	350	13.87262	352.365	0.10000	2.540	8	80
15 O.D.	375	14.87419	377.805	0.10000	2.540	8	80
16 O.D.	400	15.87575	403.245	0.10000	2.540	8	80
17 O.D.	425	16.87500	428.626	0.10000	2.540	8	80
18 O.D.	450	17.87500	454.026	0.10000	2.540	8	80
20 O.D.	500	19.87031	504.707	0.10000	2.540	8	80
22 O.D.	550	21.86562	555.388	0.10000	2.540	8	80
24 O.D.	600	23.86094	606.069	0.10000	2.540	8	80
26 O.D.	650	25.85625	656.758	0.10000	2.540	8	80
28 O.D.	700	27.85156	707.431	0.10000	2.540	8	80
30 O.D.	750	29.84687	758.112	0.10000	2.540	8	80

TABLE 5.—DRILL SIZES FOR AMERICAN TAPER PIPE TAPS FOR TAPPING WITHOUT REAMING

Size of Pipe	Threads per Inch	Root Diam. Small End of Tap in Inches	Root Diam. Small End of Pipe and Gage in Inches	Tap Drill	
				Size	Decimal Equivalent
1/8	27	0.3145	0.3339	R	0.339
1/4	18	0.4043	0.4329	7/16	0.437
3/8	18	0.5393	0.5676	37/64	0.578
1/2	14	0.6651	0.7013	23/32	0.719
3/4	14	0.8751	0.9105	59/64	0.921
1	11 1/2	1.1017	1.1441	1 5/32	1.156
1 1/4	11 1/2	1.4447	1.4876	1 1/2	1.500
1 1/2	11 1/2	1.6828	1.7265	1 47/64	1.734
2	11 1/2	2.1578	2.1995	2 7/32	2.218
2 1/2	8	2.5617	2.6195	2 5/8	2.625
3	8	3.1828	3.2406	3 1/4	3.250
3 1/2	8	3.6789	3.7375	3 3/4	3.750
4	8	4.1750	4.2344	4 1/4	4.250

BRASS TUBE SIZES FOR CHANDELIER WORK

TABLE 6.—TUBING, JOINTS AND FITTINGS FOR CHANDELIERS ARE OF THE FOLLOWING SIZES

Outside Diameter or Trade Name	Outside Diameter of Thread	Number of Threads to the Inch
1/4	0.265	27
5/16	0.327	27
3/8	0.390	27
7/16	0.452	27
1/2	0.515	27
9/16	0.577	27
5/8	0.640	27
3/4	0.765	27

French chandelier work uses tubing 11 millimeters (0.433 inch) in diameter, with a thread of 1.3-millimeter pitch, (0.05 inch or about 20 theads per inch).

TABLE 7.—DIMENSIONS OF AMERICAN STANDARD LOCKNUT THREAD

Nominal Size		*C*		*G*		Depth of Thread		Number of Threads	
Inches	Millimeters	Inches	Millimeters	Inches	Millimeters	Inches	Millimeters	Per Inch	Per 254 Millimeters
1/8	3	0.38402	9.754	0.38633	9.813	0.02963	0.753	27	270
1/4	6	0.50378	12.796	0.50725	12.884	0.04444	1.129	18	180
3/8	10	0.64090	16.279	0.64437	16.367	0.04444	1.129	18	180
1/2	13	0.79628	20.225	0.80075	20.339	0.05714	1.451	14	140
3/4	19	1.00672	25.571	1.01118	25.684	0.05714	1.451	14	140
1	25	1.26037	32.013	1.26580	32.151	0.06956	1.767	11½	115
1¼	32	1.60512	40.770	1.61055	40.908	0.06956	1.767	11½	115
1½	38	1.84407	46.839	1.84951	46.978	0.06956	1.767	11½	115
2	50	2.31801	58.877	2.32344	59.015	0.06956	1.767	11½	115
2½	64	2.79341	70.953	2.80122	71.151	0.10000	2.540	8	80
3	76	3.41975	86.862	3.42756	87.060	0.10000	2.540	8	80
3½	90	3.92006	99.570	3.92787	99.768	0.10000	2.540	8	80
4	100	4.41838	112.227	4.42619	112.425	0.10000	2.540	8	80
4½	113	4.91719	124.897	4.92500	125.095	0.10000	2.540	8	80
5	125	5.48054	139.206	5.48836	139.405	0.10000	2.540	8	80
6	150	6.53722	166.046	6.54503	166.244	0.10000	2.540	8	80
7	175	7.53359	191.354	7.54141	191.552	0.10000	2.540	8	80
8	200	8.53128	216.695	8.53909	216.893	0.10000	2.540	8	80
9	225	9.52922	242.043	9.53703	242.241	0.10000	2.540	8	80
10	250	10.65219	270.566	10.66000	270.764	0.10000	2.540	8	80
11	275	11.65063	295.927	11.65844	296.125	0.10000	2.540	8	80
12	300	12.64906	321.287	12.65688	321.485	0.10000	2.540	8	80

PIPE USED IN OIL-WELL WORK

Pipes for both oil-transmission lines and for oil-well casings have been standardized by the American Petroleum Institute, known as the A.P.I. Bessemer, open-hearth, or electric steel of good welding quality, may be used for all pipe. Open-hearth iron with an impurity content of not more than 16/100 of 1 per cent may be used. Furnace-welded pipe 3 inches or under may be butt-welded, but pipe over 3 inches must be lap-welded. Plain-end pipe for welding is usually beveled 37½ degrees, with a width of flat of 1/16 inch and a tolerance of 1/32 inch in either direction.

TABLE 8.—TAPERS AND TOLERANCES OF WELL CASINGS

	When taper per foot is specified as:		
	3/16 Inch	⅜ Inch	¾ Inch
Maximum taper, inches	¼	7/16	13/16
Minimum taper, inches	5/32	11/32	23/32

American Standard form of thread is used but is sometimes rounded, instead of flattened. For line pipe the taper is nominally ¾ inch per foot with 23/32 as a minimum and 13/16 inch as a maximum. Well casings are made with three tapers, as in Table 8. Line pipe follows standard practice. Well casings are shown in Table 9. All dimensions are in inches and measured at the standard temperature of 68°F. Casing threads are shown in Table 10. Casings have an average length of 20 feet

Standard drill pipes are from 2⅞ to 6⅝ inches outside diameter with specials of 2⅜, 7⅝, and 8⅝ inches. Dimensions are shown in Table 11, also the form of thread. Drill pipe is made in lengths of 20 to 22 feet and 27 to 30 feet.

TABLE 9.—A.P.I. STANDARD WELL CASING

(Originally established by the Committee for Uniform Clearance)

(Size of A.P.I. Casing Indicates Outside Diameter. All Dimensions in Inches at 68°F.)

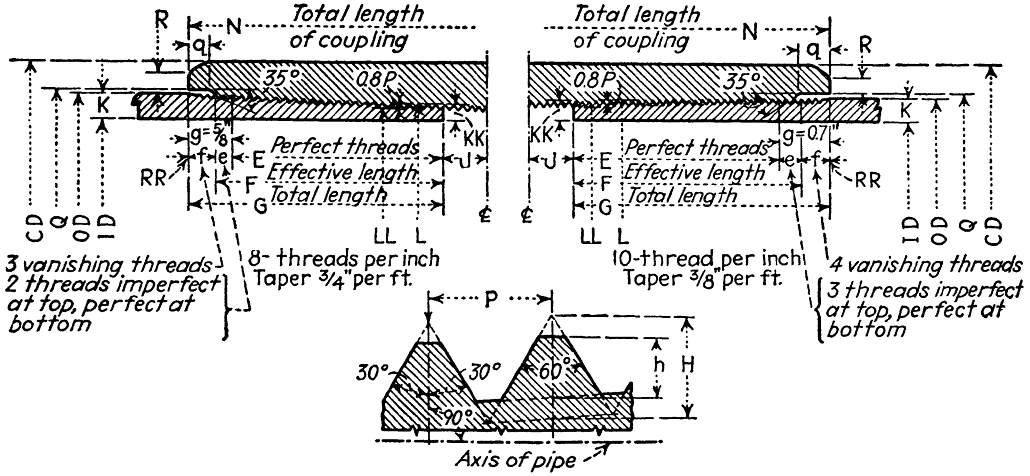
Size	Diameters			Thickness, K	Threads, Number per Inch, B	Taper, Inches per Foot, b	Weight per Foot in Pounds				Upset		Couplings				
	External, O. D.	Internal, I. D.	Upset, U. D.				Plain Ends	Threads and Couplings	Upset Casing without Couplings	Upset Casing with Threads and Couplings	Total Length, M	Nominal Length of Taper, m	Diameter for Casing Not Upset $C. D.$	Length, N	Diameter for Upset Casing, $C. D.$	Width of Bearing Face, R	Depth of Recess, q
4¾	4.75	4.082	5	0.334	10	¾	15.752	......	16.03	16.25	4⅝	1	....	7	5.65	3/16	7/16
5¾	5.75	5.29	.....	0.23	10	¾	13.559	14.00	.....	.....	. .	. .	6.5625	7½	....	¼	7/16
5¾	5.75	5.19	.....	0.28	10	¾	16.357	17.00	.....	.....	. .	. .	6.5625	7½	....	¼	7/16
5¾	5.75	5.09	.....	0.33	10	¾	19.102	19.50	.....	.....	. .	. .	6.5625	7½	....	¼	7/16
5¾	5.75	5.09	6.	0.33	10	¾	19.102	......	19.36	20.00	5⅜	1½	....	8½	6.75	¼	7/16
5¾	5.75	4.99	.....	0.38	10	¾	21.793	22.50	.....	.....	. .	. .	6.5625	7½	.....	¼	7/16
5¾	5.75	4.99	6.	0.38	10	¾	21.793	......	22.16	23.00	5⅜	1½	....	8½	6.75	¼	7/16
7⅝	7.625	6.969	.....	0.328	8	¾	25.562	26.40	.....	.....	. .	. .	8.500	8⅛	.....	¼	⅝
7⅝	7.625	6.875	.....	0.375	8	¾	29.036	29.70	.....	.....	. .	. .	8.500	8⅛	.....	¼	⅝
7⅝	7.625	6.765	.....	0.430	8	¾	33.042	33.70	.....	.....	. .	. .	8.500	8⅛	.....	¼	⅝
8⅛*	8.125	7.485	.....	0.32	10	¾	26.674	28.00	.....	.....	. .	. .	9.0937	8½	.....	9/32	7/16
8⅛*	8.125	7.385	.....	0.37	10	¾	30.645	32.00	.....	.....	. .	. .	9.0937	8½	.....	9/32	7/16
8⅛*	8.125	7.285	.....	0.42	10	¾	34.562	35.50	.....	.....	. .	. .	9.0937	8½	.....	9/32	7/16
8⅛*	8.125	7.185	.....	0.47	10	¾	38.425	39.50	.....	.....	. .	. .	9.0937	8½	.....	9/32	7/16
8⅛*	8.125	7.185	8.375	0.47	10	¾	38.425	......	38.80	40.00	5⅜	1½	....	8½	9.30	9/32	7/16

TABLE 9.—A.P.I. STANDARD CASING.—*Continued*

Size	Diameters			Thickness, *K*	Threads, Number per Inch, *B*	Taper, Inches per Foot, *b*	Weight per Foot, in Pounds				Upset		Couplings				
	External, O. D.	Internal, I. D.	Upset, U. D.				Plain Ends	Threads and Couplings	Upset Casing without Couplings	Upset Casing with Threads and Couplings	Total Length, *M*	Nominal Length of Taper, *m*	Diameter for Casing Not Upset C. *D*.	Length, *N*	Diameter for Upset Casing, C. *D*.	Width of Bearing Face, *R*	Depth of Recess, *q*
10¾	10.75	10.05	.....	0.35	8	¾	38.875	40.50	.....	.....	..	..	11.75	8½	.....	9/32	11/32
10¾	10.75	9.95	.....	0.40	8	¾	44.215	45.50	.....	.....	..	..	11.75	8½	.....	9/32	11/32
10¾	10.75	9.85	.....	0.45	8	¾	49.502	51.00	.....	.....	..	..	11.75	8½	.....	9/32	11/32
10¾	10.75	9.76	.....	0.495	8	¾	54.214	55.50	.....	.....	..	..	11.75	8½	.....	9/32	11/32
13⅜	13.375	12.715	.....	0.33	8	¾	45.976	48.00	.....	.....	..	..	14.375	9	.....	5/16	11/32
13⅜	13.375	12.615	.....	0.38	8	¾	52.739	65.50	.....	.....	..	..	14.375	9	.....	5/16	11/32
13⅜	13.375	12.515	.....	0.43	8	¾	59.449	61.00	.....	.....	..	..	14.375	9	.....	5/16	11/32
13⅜	13.375	12.415	.....	0.48	8	¾	66.105	68.00	.....	.....	..	..	14.375	9	.....	5/16	11/32
16	16.00	15.375	.....	0.3125	8	¾	52.357	55.00	.....	.....	..	..	17.00	9	.....	5/16	11/32
16	16.00	15.250	.....	0.375	8	¾	62.579	65.00	.....	.....	..	..	17.00	9	.....	5/16	11/32
16	16.00	15.125	.....	0.4375	8	¾	72.716	75.00	.....	.....	..	..	17.00	9	.....	5/16	11/32
16	16.00	15.010	.....	0.495	8	¾	81.969	84.00	.....	.....	..	..	17.00	9	.....	5/16	11/32
18⅝	18.625	17.855	.....	0.385	8	¾	75.000	78.00	.....	.....	..	..	19.75	9	.....	⅜	11/32
18⅝	18.625	17.755	.....	0.435	8	¾	84.508	87.50	.....	.....	..	..	19.75	9	.....	⅜	11/32
18⅝	18.625	17.655	.....	0.485	8	¾	93.962	96.50	.....	.....	..	..	19.75	9	.....	⅜	11/32
21½	21.50	20.71	.....	0.395	8	¾	89.034	92.50	.....	.....	..	..	22.625	9	.....	⅜	11/32
21½	21.50	20.61	.....	0.445	8	¾	100.067	103.00	.....	.....	..	..	22.625	9	.....	⅜	11/32
21½	21.50	20.51	.....	0.495	8	¾	111.046	114.00	.....	.....	..	..	22.625	9	.....	⅜	11/32
24½	24.50	23.75	.....	0.375	8	¾	96.622	100.50	.....	.....	..	..	25.625	9	.....	⅜	11/32
24½	24.50	23.65	.....	0.425	8	¾	109.278	113.00	.....	.....	..	..	25.625	9	.....	⅜	11/32

[a] This size inactive; available on special order only.

TABLE 10.—A.P.I. STANDARD CASING THREADS
(All dimensions in Inches at 68°F.; All Weights in Pounds)

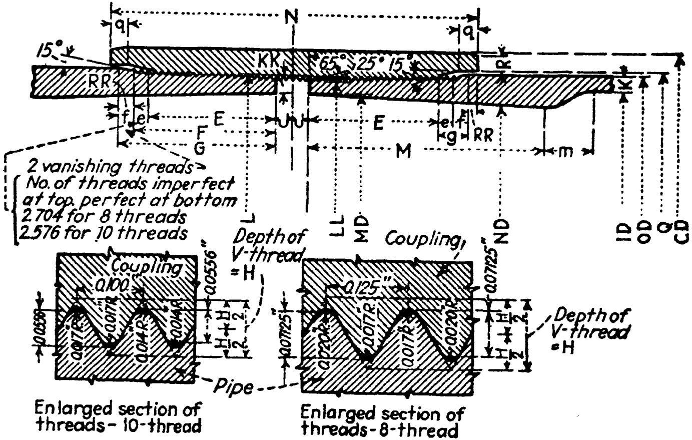


Enlarged section of thread

Casing			Threads											
Size	External Diameter O. D.	Weight per Foot Complete	Number per Inch, *B*	Included Taper, in Inches per foot, *b*	Length of Perfect, *E*	Number of Perfect	Effective Length, *F*	Total Length, *G*	Height of Thread Truncated, *h*	Diameter of Casing at Root of Threads, *L-L*	Diameter of Casing Top of Threads, *L*	End of Pipe to Center of Coupling, Made Up, *J*	Distance End of Coupling beyond last Scratch, Made Up, *R-R*	Stand-Off of Coupling at Hand-tight Fit, *A*
5¾	5.750	All	10	¾	2.4250	24.25	2.725	3.125	0.0800	5.514	5.674	0.625	0.000	
7⅝	7.625	All	8	¾	2.6250	21.00	2.875	3.250	0.1000	7.261	7.461	0.6875	0.125	
8⅛*	8.125	All	10	¾	2.9250	29.25	3.225	3.625	0.0800	7.874	8.034	0.625	0.000	
10¾	10.750	All	8	¾	3.0000	24.00	3.250	3.625	0.1000	10.363	10.563	0.625	0.000	
10⅜	13.375	All	8	¾	3.2500	26 00	3.500	3 875	0.1000	12.972	13.172	0.625	0.000	
16	16.000	All	8	¾	3.2500	26.00	3.500	3.875	0.1000	15.597	15.797	0.625	0.000	
18⅝	18.625	All	8	¾	3.2500	26.00	3.500	3.875	0.1000	18.222	18.422	0.625	0.000	
21½	22.500	All	8	¾	3.2500	26.00	3.500	3.875	0.1000	21.097	21.297	0.625	0.000	
24½	24.500	All	8	¾	3.2500	26.00	3.500	3.875	0.1000	24.097	24.297	0.625	0.000	

* This size inactive; available on special order only.

TABLE 11.—A.P.I. STANDARD DRILL-PIPE THREADS*
(Size of Drill Pipe Indicates Outside Diameter; All Dimensions in Inches at 68°F.)



NOTES TO TABLE 11

Interchangeability.—The adoption of the specified dimensions for A.P.I. drill-pipe threads minimizes the difficulties of introducing this new standard, for, had the Briggs pitch diameter been retained large stocks of tools already in use and threaded to the larger diameter adopted by the National Tube Company would have been too loose a fit on A.P.I. drill pipe.

Pitch Diameter.—The actual pitch diameter adopted conforms to that in use by the National Tube Company in recent years. The tabulated figure is that dimension determined by measurement of the pitch diameter at the gage point with a thread micrometer. These values may be computed for 8-pitch threads by subtracting from the nominal outside diameter of the pipe the depth of the A.P.I. thread, plus 0.003 inch, which has been allowed for clearance, thus:

$$\text{P.D.} = \text{O.D.} - (h + 0.003).$$

SPECIAL NOTE

Dimension *A*—The stand-off *A* specified does not apply to materials used with drill pipe, such as tool joints, drill collars, etc., except where such materials have the same recess dimensions as the drill-pipe couplings.

Size	Outside Diameter, O. D.	Weight in Pounds per Foot Finished	No. Threads per Inch, *B*	Included Taper, in Inches per Foot, *b*	Total Length of Threads, *G*	Length of Threads to Gage Point, Length of Perfect Threads, *E*	Length of Vanishing Plus Imperfect Threads, *g*	Height of Threads. (Truncated), *h*	Diameter at End of Pipe to Root of Threads, *L-L*	Diameter at End of Pipe to Crest of Threads, *L*	Distance End of Coupling beyond Last Scratch. Made Up by Power, *R-R*	Threads Allowed for Make-up and Creep	Distance End of Pipe to Center of Coupling. Made Up, *J*	Stand-Off of Coupling at Hand-tight Fit, *A*
2 3/8†	2.375	4.800	10	3/4	2.125	1.667	0.458	0.05560	2.206	2.317	1/16″	7	9/16	3 threads
2 3/8	2.375	6.650	8	3/4	2.125	1.537	0.588	0.07125	2.130	2.273	1/16″	7	9/16	3 threads
2 7/8	2.875	All	8	3/4	2.625	2.037	0.588	0.07125	2.599	2.742	1/16″	7	9/16	3 threads
3 1/2	3.500	All	8	3/4	2.625	2.037	0.588	0.07125	3.224	3.367	1/16″	7	9/16	3 threads
4 1/2	4.500	All	8	3/4	3.375	2.787	0.588	0.07125	4.177	4.320	1/16″	7	9/16	3 threads
5 9/16‡	5.563	All	8	3/4	3.625	3.037	0.588	0.07125	5.225	5.067	1/16″	7	9/16	3 threads
6 5/8	6.625	All	8	3/4	3.875	3.287	0.588	0.07125	6.271	6.414	1/16″	7	9/16	3 threads
7 5/8§	7.625	All	8	3/4	4.250	3.662	0.588	0.07125	7.248	7.390	1/16″	7	9/16	3 threads
8 5/8§	8.625	All	8	3/4	4.625	4.037	0.588	0.07125	8.224	8.367	1/16″	7	9/16	3 threads

* These values apply to right- or left-hand threads. Pipe manufacturers producing drill pipe with left-hand threads need not acquire certified gages unless they desire to use the monogram on this pipe.

† On special order only.

‡ Outside diameter of 5 9/16 inches is 5.563 inches.

§ Tentative; special order only.

Gage tolerances are shown in Table 12.

TABLE 12.—TOLERANCES FROM BASIC ON GAGES FOR CASING, DRILL PIPE AND TUBING
(All Dimensions in Inches at 68°F., except Thread Angles, Which Are in Minutes of Arc)

Item	Tolerances	
	For ⅜ Inch Taper*	For ¾ Inch Taper*
Pitch diameter on plugs	±.0005	±.0010
Lead on plugs	±.0003	±.0005
Lead on rings	±.0005	±.0008
Taper on plugs	±.0005 −.0000	±.0010 −.0000
Taper on rings	−.0002 −.0012	−.0002 −.0012
½ thread angle on plugs	±10′	±10′
½ thread angle on rings	±15′	±15′

* Taper, as used herein, means *total* or measured on the diameter.

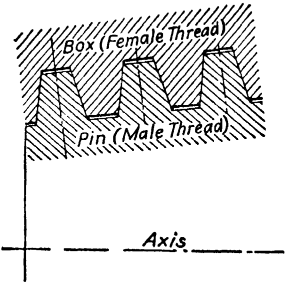


FIG. 15.—Hughes Oil Tool Acme Thread for Oil Tools

Hughes Acme Thread Tool Joint

The Hughes "Acme" tool joint thread is cut normal to the *slope* of the *taper* as shown. The threads are 4 per inch. Clearance top and bottom of thread = 0.010 inch. The taper of this joint = 8 degrees with center line or 16 degrees included angle. There is 3⅜ inch taper per foot.

BRITISH STANDARD PIPE THREADS[1]

British pipe ends are shown in Fig. 16 and gaged with a plain tapered ring gage, Fig. 17. The step is the tolerance. Pitch and form of thread are checked with a profile or comb gage. Inside thread diameters of couplings and fittings are checked by gages having threads with sharp angles that will bear only on the roots of the threads. Such a gage is shown in Fig. 18. The distance from *C* to *D* is the difference between columns 10 and 11 in the table. When screwed in by hand, *C* must go inside coupler and *D* must remain outside. The gage in Fig. 17 is used in the same way.

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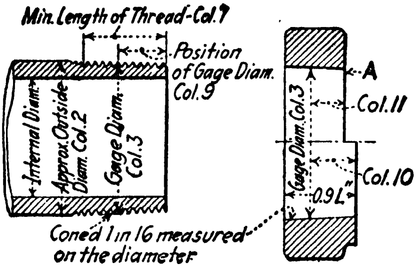
[1] By permission British Engineering Standards Committee.


Min. Length of Thread-Col. 7
L
Position of Gage Diam. Col. 9
Internal Diam.
Approx. Outside Diam. Col. 2
Gage Diam. Col. 3
Coned 1 in 16 measured on the diameter
A
Col. 11
Gage Diam. Col. 3
Col. 10
0.9L"

FIGS. 16 and 17.—British Pipe and Ring Gage

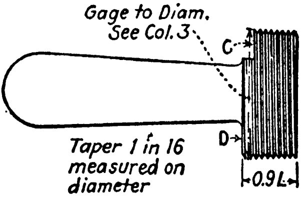


FIG. 18.—British Plug Gage

The Three-Wire Method of Measuring Pitch Diameter of Taper Pipe Threads

In the measurement of the pitch diameter of a taper pipe thread, it is necessary to locate one measuring wire at a definite position on the taper. This may be at any convenient length (*L*) from the end of the thread.

A known position can be located with a 60-degree gage block accessory point as shown in Fig. 18*a* at *A*. A combination of blocks is made such that the cone point is a known distance above a surface plate, say 0.250 inch, and the thread gage is moved into contact with the cone point and rotated until the cone point excludes light on both sides of the thread. A mark is then placed on the side of the next thread with a soft lead pencil, prussian blue, or similar marking device.

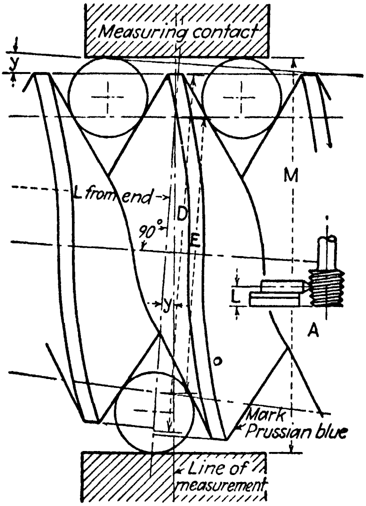


FIG. 18*a*.—The 3-Wire Method of Measuring Pitch Diameter of Taper Pipe Threads.

One wire is then placed in the thread at the known distance from the end and the two other wires are placed opposite. The reading over the three wires will be at an angle to the axis of the thread, and therefore the following formula must be used:

$$E = 1.00049\,M - \left(3G - \frac{0.86602}{n}\right)$$

or

$$E = 1.00049\,M - \text{best wire constant}$$

The pitch diameter at any other point is then computed by adding or subtracting the amount of taper from the diameter measured to the diameter desired. The taper is 0.0625 inch per inch on diameter.

Example.—Three-wire method of measuring pipe threads.

Given: A ½-inch 14-taper pipe thread gage.

One wire is located 0.250 inch from small end.

14 pitch best wire diameter = 0.04124 inch
Best wire constant = 0.06186 inch
Measurement over three wires = 0.8360 inch

Computations: E = 1.00049 × 0.8360 inch − 0.06186 inch
= 0.83641 inch
−0.06186 inch

E at 0.250 inch = 0.77455 inch

E at gaging notch 0.320 inch from end = 0.77455 inch + (0.320 inch − 0.250 inch) × 0.0625 inch
= 0.77455 inch + 0.070 inch × 0.0625 inch
= 0.77455 inch
+0.00438 inch
= 0.77893 inch

Basic E at gaging notch = 0.77843 inch

Amount oversize = 0.00050 inch

The Two-Wire Method of Measuring Pitch Diameter of Taper Pipe Threads

In the two-wire method, the micrometer or measuring instrument is constrained so that the measuring surfaces are parallel to the axis of the thread. One wire is then located at a known distance from the end of the thread, and the other wire is placed opposite a half-thread distance toward the small end of the taper and then opposite a half thread distance toward the large end of the taper. Two measurements are made, and the average of these two is used instead of 1.00049 M. The two-wire method is more accurate than the three-wire method because it measures the actual taper of the thread. It also simplifies computations.

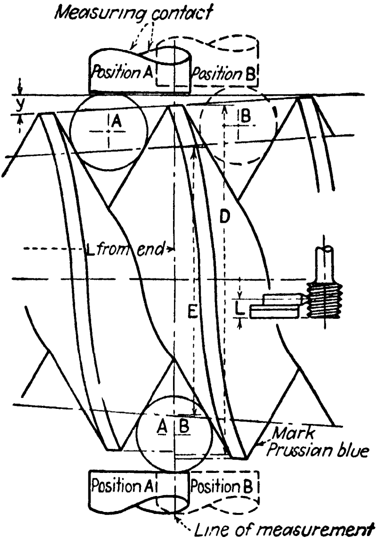


FIG. 18*b*.—The 2-Wire Method of Measuring the Pitch Diameter of Taper Pipe Threads.

The pitch diameter at any other point is then computed by adding or subtracting the amount of taper from the diameter measured to the diameter desired. The taper is 0.0625 inch per inch on diameter.

EXAMPLE.—Two-wire method of measuring pipe threads.
Given: A 1 inch = 11½ taper pipe thread gage.
One wire is located 0.300 inch from small end.

11½ pitch best wire diameter = 0.05020 inch
Best wire constant = 0.07529 inch
Measurement over wires (small) = 1.3065 inch
Measurement over wires (large = 1.3093 inch
Measurement over wires (average) = 1.3079 inch

Formula *E* = Average measurement − best wire constant

Computations: *E* = 1.3079 inch − 0.07529 inch
= 1.3079 inch
−0.07529 inch

E at 0.300 inch = 1.23261 inch
E at gaging notch 0.400 inch from small end = 1.23261 inch + (0.400 − 0.300) × 0.0625 inch
= 1.2361 inch + 0.00625 inch
= 1.23261 inch
+0.00625 inch

E at gaging notch . = 1.23886 inch
Basic *E* at gaging notch = 1.23863 inch

Amount oversize = 0.00023 inch

TABLE 13.—BRITISH STANDARD PIPE THREADS
(Dimensions in Inches)

1	2	3	4	5	6	7	8	9	10	11
Nominal Bore of Tube	Approximate Outside Diameter of Black Tube	Gage Diameter (*See* Fig. 16.	Depth of Thread	Core Diameter, Measured at Same Distance from End of Pipe as the Gage Diameter	Number of Threads per Inch	Length of Thread		Distance of Gage Diameter from Pipe End (Class I. Taper Screw)		
						L On Pipe End Min.	In Coupler Min.	Standard	Max.	Min.
1/8	13/32	0.383	0.0230	0.337	28	3/8	3/4	5/32	0.18	0.13
1/4	17/32	0.518	0.0335	0.451	19	7/16	7/8	3/16	0.22	0.16
3/8	11/16	0.656	0.0335	0.589	19	1/2	1	1/4	0.29	0.21
1/2	27/32	0.825	0.0455	0.734	14	5/8	1 1/4	1/4	0.29	0.21
5/8	15/16	0.902	0.0455	0.811	14	5/8	1 1/4	1/4	0.29	0.21
3/4	1 1/16	1.041	0.0455	0.950	14	3/4	1 1/2	3/8	0.44	0.31
7/8	1 7/32	1.189	0.0455	1.098	14	3/4	1 1/2	3/8	0.44	0.31
1	1 11/32	1.309	0.0580	1.193	11	7/8	1 3/4	3/8	0.44	0.31
1 1/4	1 11/16	1.650	0.0580	1.534	11	1	2	1/2	0.58	0.42
1 1/2	1 29/32	1.882	0.0580	1.766	11	1	2	1/2	0.58	0.42
1 3/4	2 5/32	2.116	0.0580	2.000	11	1 1/8	2 1/4	5/8	0.73	0.52
2	2 3/8	2.347	0.0580	2.231	11	1 1/8	2 1/4	5/8	0.73	0.52
2 1/4	2 5/8	2.587	0.0580	2.471	11	1 1/4	2 1/2	11/16	0.80	0.57
2 1/2	3	2.960	0.0580	2.844	11	1 1/4	2 1/2	11/16	0.80	0.57
2 3/4	3 1/4	3.210	0.0580	3.094	11	1 3/8	2 3/4	13/16	0.95	0.68

3	3½	3.460	0.0580	3.344	11	1⅜	2¾	11/16	0.95	0.68
3¼	3¾	3.700	0.0580	3.584	11	1½	3	⅞	1.02	0.73
3½	4	3.950	0.0580	3.834	11	1½	3	⅞	1.02	0.73
3¾	4¼	4.200	0.0580	4.084	11	1½	3	⅞	1.02	0.73
4	4½	4.450	0.0580	4.334	11	1⅝	3¼	1	1.17	0.83
4½	5	4.950	0.0580	4.834	11	1⅝	3¼	1	1.17	0.83
5	5½	5.450	0.0580	5.334	11	1¾	3½	1⅛	1.31	0.94
5½	6	5.950	0.0580	5.834	11	1⅞	3¾	1¼	1.46	1.04
6	6½	6.450	0.0580	6.334	11	2	4	1⅜	1.60	1.15
7	7½	7.450	0.0640	7.322	10	2⅛	4¼	1⅜	1.60	1.15
8	8½	8.450	0.0640	8.322	10	2¼	4¼	1½	1.75	1.25
9	9½	9.450	0.0640	9.322	10	2¼	4½	1½	1.75	1.25
10	10½	10.450	0.0640	10.322	10	2⅜	4¾	1⅝	1.90	1.35
11	11½	11.450	0.0800	11.290	8	2½	5	1⅝	1.90	1.35
12	12½	12.450	0.0800	12.290	8	2½	5	1⅝	1.90	1.35
13	13¾	13.680	0.0800	13.520	8	2⅝	5¼	1⅝	1.90	1.35
14	14¾	14.680	0.0800	14.520	8	2¾	5½	1¾	2.04	1.46
15	15¾	15.680	0.0800	15.520	8	2¾	5½	1¾	2.04	1.46
16	16¾	16.680	0.0800	16.520	8	2⅞	5¾	1⅞	2.19	1.56
17	17¾	17.680	0.0800	17.520	8	3	6	2	2.33	1.67
18	18¾	18.680	0.0800	18.520	8	3	6	2	2.33	1.67

On low-pressure copper tube work 20 threads per inch is used on sizes from ¼ to 1½ inches and 16 threads from 1¾ to 4 inches.

TABLE 14.—METRIC PIPE THREADS

Nominal Inside Pipe Diameter in Inches	Inside Pipe Diameter in Millimeters	External Thread Diameter in Millimeters	Internal Thread Diameter in Millimeters	Number of Threads per Inch
⅛		10	8.3	28
¼	6.35	13	11.3	19
⅜	9.52	16.5	14.8	19
½	12.70	20.5	18.2	14
⅝	15.87	23	20.7	14
¾	19.05	26.5	24.2	14
1	25.40	33	30	11
1¼	31.75	42	39	11
1½	38.10	48	45	11
1¾	44.45	52	49	11
2	50.30	59.7	56.7	11
2½	63.50	76	73	11
3	76.20	89	86	11
3½	88.90	101.5	98.5	11
4	101.60	114	111	11

NATIONAL (AMERICAN) STANDARD FIRE-HOSE COUPLING SCREW THREAD

This standard covers the threaded part of fire-hose couplings, hydrant outlets, stand-pipe connections, Siamese connections, and all other special fittings on fire lines where fittings of 2½, 2, 3½, and 4½ inches nominal diameter are used. It should be noted also that they determine the size of the finished product and not of the threading tools. The Standard fire-hose coupling screw thread is the American (National) Standard form.

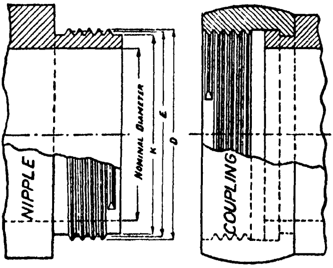


FIG. 19.—Standard Hose Couplings

TABLE 15.—CHARACTERISTICS OF THE NATIONAL STANDARD FIRE-HOSE COUPLING SCREW THREAD
(All Dimensions in Inches)

C Nominal inside diameter of hose coupling	$2\frac{1}{2}$	3	$3\frac{1}{2}$	$4\frac{1}{2}$
N Number of threads per inch	$7\frac{1}{2}$	6	6	4
L Total length of threaded part of coupling and hydrant nipple, external thread	1	$1\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{1}{4}$
I Distance from face of nipple to start of second turn	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{7}{16}$
H Depth of coupling swivel to washer seat	$\frac{15}{16}$	$1\frac{1}{16}$	$1\frac{1}{16}$	$1\frac{3}{16}$
J Distance from face of coupling swivel to start of second turn	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{8}$
T Depth of thread of coupling swivel	$\frac{11}{16}$	$\frac{13}{16}$	$\frac{13}{16}$	$\frac{15}{16}$

TABLE 16.—LIMITING DIMENSIONS FOR THREADS OF COUPLING SWIVELS AND HYDRANT CAPS (INTERNAL[1])
(All Dimensions in Inches)

Nominal Size	No. of Threads per Inch	Min. Major Diameter[2]	Pitch Diameter		Minor Diameter	
			Max.	Min.	Max.	Min.
2.500	7.5	3.0836	3.0130	2.9970	2.9424	2.9104
3.000	6.0	3.6389	3.5486	3.5306	3.4583	3.4223
3.500	6.0	4.2639	4.1736	4.1556	4.0833	4.0473
4.500	4.0	5.7859	5.6485	5.6235	5.5111	5.4611

TABLE 17.—LIMITING DIMENSIONS OF THREADS OF COUPLING AND HYDRANT NIPPLES (EXTERNAL[1])
(Dimensions in Inches)

Nominal Size	No. of Threads per Inch	Major Diameter		Pitch Diameter		Max. Minor Diameter[3]
		Max.	Min.	Max.	Min.	
2.500	7.5	3.0686	3.0366	2.9820	2.9660	2.8954
3.000	6.0	3.6239	3.5879	3.5156	3.4976	3.4073
3.500	6.0	4.2439	4.2079	4.1356	4.1176	4.0273
4.500	4.0	5.7609	5.7109	5.5985	5.5735	5.4361

The largest nipple is purposely made smaller in diameter than the smallest coupling in order to insure a fit loose enough so that these threads can be assembled quickly regardless of the presence of dirt, burrs, bruises, etc.

[2] These dimensions correspond to the basic flat ($\frac{1}{8}p$). The profile at the major diameter of the coupling, produced by a worn tool, must not fall below the basic outline, but a new tool may be made with a flat at the point as small as $\frac{1}{24}p$ (p = pitch of thread).

[3] These dimensions are figured to the intersection of the worn-tool arc with a center line through crest and root. New tools may be made to give a minimum minor diameter of the nipple as small as that corresponding to a flat of $\frac{1}{24}p$.

TABLE 18.—LIMITING DIMENSIONS OF FIELD INSPECTION PLUG SCREW THREAD GAGES FOR COUPLING SWIVELS AND HYDRANT CAPS (INTERNAL)
(Dimensions in Inches)

Nominal Size	No. of Threads per Inch	"Go" or Minimum Gage				"Not Go" or Maximum Gage			
		Major Diam.		Pitch Diam.		Major Diam.		Pitch Diam.	
		Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
2.500	7.5	3.0846	3.0836	2.9980	2.9970	3.0836	3.0826	3.0130	3.0120
3.000	6.0	3.6399	3.6389	3.5316	3.5306	3.6389	3.6379	3.5486	3.5476
3.500	6.0	4.2649	4.2639	4.1566	4.1556	4.2639	4.2629	4.1736	4.1726
4.500	4.0	5.7869	5.7859	5.6245	5.6235	5.7859	5.7849	5.6485	5.6475

NOTES.—(*a*) The minor diameters of plug thread gages are undercut below the nominal minor diameter to give clearance for grinding or lapping.

(*b*) The allowance variation in lead between any two threads not farther apart than the length of engagement is ± 0.0005 inch.

(*c*) The allowable variation in one-half angle of thread is ± 10 minutes.

(*d*) The diameters of the "not go" field inspection plain plug gages are the same as those given for the maximum minor diameter of couplings given in Table 15.

Gaging Standard Fire-Hose Coupling Screw Threads

National (American) Standard Fire-Hose Coupling Screw Thread will be inspected in the field by plug and ring gages made within the limiting dimensions given in Tables 17 to 19. These will be in the hands of the representative of the purchaser, who will in most cases be the Fire Chief or the Superintendent of Water Works, or both.

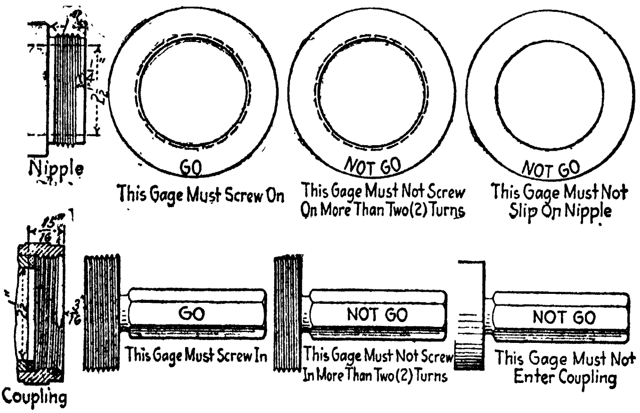

Nipple
GO
This Gage Must Screw On
NOT GO
This Gage Must Not Screw On More Than Two(2) Turns
NOT GO
This Gage Must Not Slip On Nipple
GO
This Gage Must Screw In
NOT GO
This Gage Must Not Screw In More Than Two(2) Turns
NOT GO
This Gage Must Not Enter Coupling
Coupling

FIG. 20.—Gages for Standard Hose Couplings

The manufacturers' gages should, therefore, be made an appreciable amount within the limiting dimensions of these field inspection gages, by whatever amount may be desired, so as to allow for gage wear and also to avoid, as far as possible, disagreements which might otherwise arise due to slight differences in the dimensions of the gages.

Table 19.—Limiting Dimensions of Field Inspection Ring Screw Thread Gages for Coupling and Hydrant Nipples (External)
(Dimensions in Inches)

Nominal Size	No. of Threads per Inch	"Go" or Maximum Gage				"Not Go" or Minimum Gage			
		Pitch Diam.		Minor Diam.		Pitch Diam.		Minor Diam.	
		Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
2.500	7.5	2.9820	2.9810	2.9104	2.9094	2.9670	2.9660	2.9114	2.9104
3.000	6.0	3.5156	3.5146	3.4223	3.4213	3.4986	3.4976	3.4233	3.4223
3.500	6.0	4.1356	4.1346	4.0473	4.0463	4.1186	4.1176	4.0483	4.0473
4.500	4.0	5.5985	5.5975	5.4611	5.4601	5.5745	5.5735	5.4621	5.4611

Notes.—(*a*) The major diameters of the ring thread gages are undercut beyond the nominal major diameters to give clearance for grinding or lapping.

(*b*) The allowable variation in lead between any two threads not farther apart than the length of engagement is ±0.0005 inch.

(*c*) The allowable variation in one-half angle of thread is ±10 minutes.

(*d*) The diameters of the "not go" field inspection plain ring gages are the same as those given for the minimum major diameter of nipples given in Table 16.

Pipe Threads for Rail Fittings

New standards for pipe threads will include those used for rail fittings. The same pipe threads will be used for each diameter of pipe, but the thread is shorter to permit the use of the larger diameter of the thread and add strength to the joint.

On pipe up to and including 2 inches, the three end threads are omitted, and on pipe from 2 to 4 inches, there are four threads omitted from the end of the pipe.

Plug and ring gages for these rail joints will be made to correspond to the shorter threads.

SECTION III

DRILLING[1]

Two fluted twist drills are standard tools for cutting holes in solid metal. Drills with three or four flutes are used for enlarging cored holes. The flutes are usually milled from the solid and are frequently polished to help chip removal. Twist drills are made with a slight taper from the point to the shank, being about 0.0005 inch smaller per inch of length, back of the point. Drills are seldom depended upon to give highly accurate holes as the hole drilled depends upon the way the drill is ground and upon the material being drilled. Plastics and similar materials seem to close in after the hole is drilled or tapped. While reamers usually give more accurate holes than drills, extreme accuracy is only secured by single point (sometimes called "diamond") boring, grinding, or lapping. Figure 1 shows five common drill shanks.

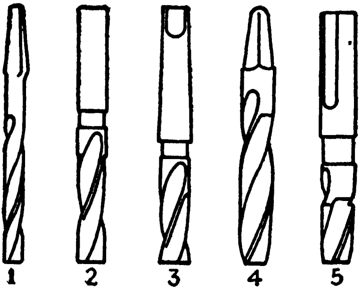


FIG. 1.—Five Common Drill Shanks: 1, Bit Stock; 2, Straight; 3, Taper with Tang; 4, Ratchet; 5, Blacksmith

Drill sizes are designated in four ways: By numbers, No. 80 to No. 1 (0.0135 to 0.228 inch); by letters, from A to Z (0.234 to 0.413 inch); by fractions from $\frac{1}{64}$ to $3\frac{1}{2}$ inches, by sixty-fourths from $\frac{1}{8}$ to $1\frac{3}{4}$, by thirty-seconds from $1\frac{25}{32}$ to $2\frac{1}{4}$, and by sixteenths from $2\frac{5}{16}$ to $3\frac{1}{2}$; and by millimeters from 0.5 to 10 millimeters, by tenths of millimeters, up to 10 millimeters, and by half millimeters on larger sizes. All four designations are combined in one table on page 137.

Most drills larger than $\frac{1}{2}$ inch in diameter are made with taper shanks. These shanks have been adopted as a standard by the

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[1] Many of the new data in this section are due to T. F. Githens, Engineer of Cleveland Twist Drill Company.

American Standards Association, and are in universal use. Taper shank standards are given later in Sec. XVII. Sizes below ½ inch are usually in the straight shank style because they are more economical to buy this way. Many satisfactory drill chucks for driving these straight shank drills are on the market.

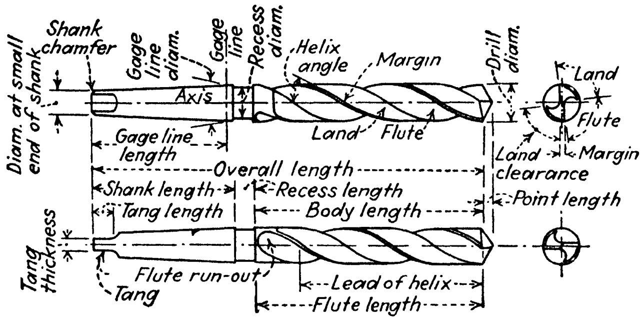


FIG. 2.—Names of Drill Parts

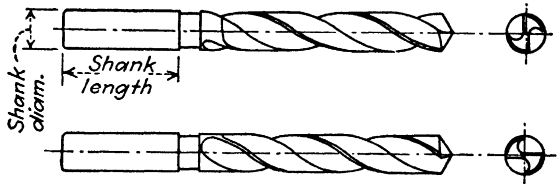


FIG. 3.—Straight Shank Drill

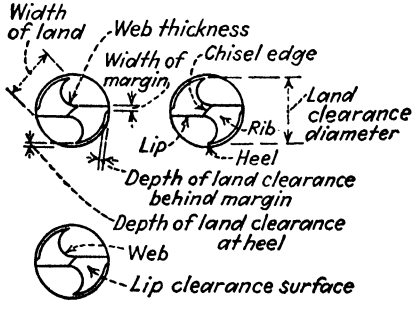


FIG. 4.—Names of Drill Point Parts

Twist drills are end-cutting tools used for originating or enlarging holes. They are made by forming, in a cylindrical piece of steel, two equal and opposite helical grooves or flutes of such shape as to allow suitable cutting edges on the cone-shaped end, to provide channels for the egress of chips, and to permit the lubricant to get to the cutting edges when the drill is working in a hole.

There are three main parts of the twist drill: the shank, the body and the point (see Figs. 2 to 5).

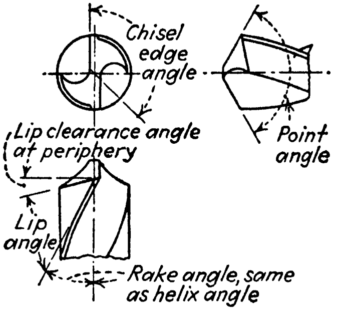

Chisel edge angle
Lip clearance angle at periphery
Point angle
Lip angle
Rake angle, same as helix angle

FIG. 5.—Cutting and Clearance Angles

DRILL NOMENCLATURE

SHANK TERMS

The shank is that portion of the drill by which it is held in the chuck or spindle. It may be cylindrical, tapered, square or otherwise.

Taper Shank.—This is generally a Morse taper which is in universal use.

Straight Shank.—The straight shank is nominally the same diameter as the drill.

Square Shank.—The square shank is a tapered square for use in bit brace or ratchet.

Shank Length.—Measured along the axis from the end of the recess to the extreme end of the shank on taper shanks, and from end of flutes on small straight shank drills which have no recess.

Taper Shank Size.—Determined by diameter at gage line and diameter at small end. Values are given in tables of tapers in drill catalogs. Morse tapers are given in section XVIII.

Tang.—Sometimes called "tongue." A flatted portion on the end of the shank to fit a special holder to assist in driving the drill. May be on either straight or taper shank but is most common on the latter. Tang is not intended to carry the entire torque load of drilling.

Tang Length.—Measured along the drill axis from the extreme end to where the radius runs out.

Tang Thickness.—Distance between flat surfaces.

Driving Flats.—One or more flats milled on a straight shank to fit a special chuck to assist in driving.

BODY TERMS

Body.—Part of the drill between the shank and the point, but not including either of them.

Axis.—Line about which the drill revolves. The longitudinal center line.

Overall Length.—From shank end to the outer corners of the cutting lips. Does not include conical cutting point.

Recess or Neck.—Part between the body and the shank. Formed on the larger size drills only. Generally smaller than the body. Commonly used for stamping size, kind of steel, and maker's name.

Body Diameter.—Diameter of the drill measured across the margins, just behind the point.

Body Back Taper.—Slight taper of body making it smaller at the shank end to reduce friction. Sometimes called longitudinal or body clearance or relief. Usually about 0.0005 inch per inch of length.

Flute.—A groove, either helical or straight, extending from the point almost to the recess. A drill may have one or more flutes.

Flute Length.—Measured along the axis, from the back end of the flutes to outer corners of the point.

Flute Run-out.—Where the bottom of the flute rises to join the body periphery.

Web.—Central portion of the body that joins the ribs. Front end of the web forms the chisel edge and is the supporting section of the drill. It gradually increases in thickness toward the shank.

Web Thickness.—The least dimension between the bottoms of the flutes. Generally measured at the point.

Web Increase.—Increase in web thickness from the point of the drill to the back end of the flutes; generally expressed as included taper per inch, in thousandths of an inch per inch.

Rib.—Metal portions of the drill body between the flutes. They provide strength and rigidity to the drill.

Land.—The periphery of that portion of the drill body not cut away by the flutes.

Margin.—The narrow strips protruding above the land clearance along the leading edges of the lands. They determine the diameter of the drill.

Width of Margin.—The width measured at the body diameter, at right angles to the helix angle, and along a chord from one edge of the circumferential margin to the other.

Heel.—Back edge of the rib formed by the intersection of the flute and the land clearance surface.

Land or Body Clearance.—That portion of the rib that has been cut away so it will not rub against the walls of the hole.

Depth of Clearance.—Amount the land has been recessed to form the clearance.

Radial Clearance.—Depth of clearance that is the same at all points along the land.

Eccentric Clearance.—Clearance increases uniformly from the margin to the heel of the adjacent flute.

Clearance Diameter.—Diameter of the cleared part of the land measured across the heels.

Helix Angle of Flutes.—Angle of leading edge of land with the axis of drill. Some are made with uniformly *decreasing* helix angle from point to shank.

Lead of Flutes.—Linear distance measured along the axis between corresponding points on the flute in one complete turn of the flutes.

POINT TERMS

Drill Point.—The entire cone shaped portion at the cutting end of the drill. The surfaces are ground to form sharp cutting edges.

Chisel Edge.—Short line across the point connecting the bottoms of the flutes.

Lip.—Cutting edges of drill extending from chisel edge to the periphery.

Point Angle.—Angle included between the cutting lips.

Lip Clearance.—Shape of the drill point back of the cutting edge. At any point of the cutting edge it is the angle between a tangent to the surface at that point and a line at right angles to the axis of the drill.

Lip-Clearance Angle at the Periphery.—Angle between a tangent on the surface back of the cutting edge at the periphery, and a line at right angles to the axis of the drill.

Rake Angle (in relation to work).—Angle between the leading edge of the land and the axis at the drill point.

DRILL-POINT GRINDING

Fully 95 per cent of drilling troubles are due to improper grinding of the point. It is important that every mechanic learn how a drill point should be ground.

To get the maximum efficiency and full life of a properly made and tempered drill, it must be properly ground at the point. This point must have (1) both lips at same angle to the axis of the drill, Fig. 6; (2) both lips the same length, Fig. 6; (3) correct amount or angle of clearance, Fig. 7; (4) correct shape of clearance, Fig. 8.

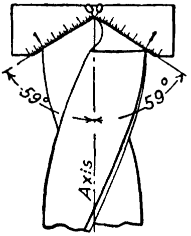


FIG. 6.—Correctly Ground Lips

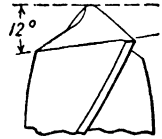


FIG. 7.—Lip Clearance

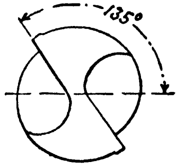


FIG. 8.—Cutting Angles

Experience shows that 12 degrees, Fig. 7, is the best angle of lip clearance, *at the periphery of the drill.* This angle should be increased gradually as the center of the drill is approached, and when the point is correctly ground, the line across the center of the web stands at an angle of approximately 135 degrees with the cutting edges as shown in Fig. 8. The failure to give sufficient angle of lip clearance at the center of the drill is the principal cause of splitting drills up the web.

The cutting edges must be at equal angles and of equal length. When the point is central but the angles of the cutting edges are different, the drill will bind on the side of the hole opposite to the lip which is cutting. It will drill too large a hole, and all the work will fall on the one cutting edge. Figure 9 illustrates this condition.

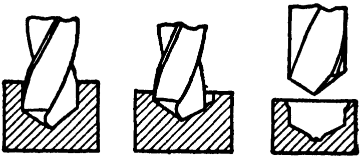


FIG. 9 FIG. 10 FIG. 11

FIGS. 9–11.—Point with Unequal Lips

When the point is ground with equal angles but with cutting edges of different lengths, the point will no longer be central and the condition shown in Fig. 10 will result.

When both angle and length of cutting edges are wrong, the drill will be laboring under the severe conditions shown in Fig. 11.

Every point of a drill lip when at work travels in a helix. Each point travels in a helix of the same lead but with a different diameter, depending on its distance from the axis. A point near the axis travels on a helix of larger angle than one near the periphery, hence the clearance should be greater nearer the center than at the periphery.

In Fig. 12 *A*, *B*, *C*, *D*, *E*, and *O* represent the cutting edge of a drill. As the drill makes one revolution, the cutting edge moves forward the depth of feed. Line *AM* represents the feed, and *MO* the circumference of the drill. Angle *AOM* represents the helix angle of the helix over which point *A* travels, and also represents the minimum lip-clearance angle at point *A* for this feed.

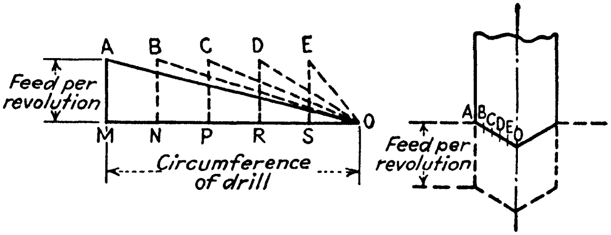


FIG. 12.—Varying Clearance Angle of Drill Point

For point *E*, the feed is still the same, but the circumference *SO* is much smaller, and the helix angle *EOS* is much greater. Thus the clearance angle ground on the lip should be greater nearer the center than at the periphery.

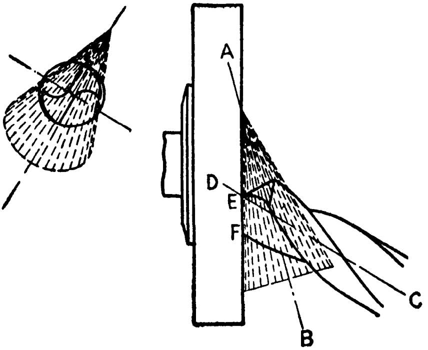


FIG. 13.—Practical Way to Get Clearance

Many attempts have been made to sharpen twist drills with this theoretically correct clearance. One way would be to revolve the drill on its axis and reciprocate it with a cam, so that every point of the lip followed its proper helix. In practice this weakens the chisel edge, unless compensating motions are used.

The most practical way to obtain this drill point clearance is to use a type of machine which grinds a segment of a cone, as in Fig. 13, about an axis *AB* which is at an angle to both the drill lip *EF* and the axis of the drill *CD*. Axis *AB* is also a slight amount above the drill axis. When one lip is ground, the drill must be removed and the other lip placed in position for grinding. Here points near the center of the drill oscillate about shorter arcs and receive more clearance than points near the periphery.

A similar type of point formed in a slightly different manner is shown in Fig. 14. Here the lip clearance is generated as a segment of a cone in a different way by revolving the drill about axis *MN*. This axis is at an angle to drill axis *PQ* and is also offset below the drill axis. Rotation about axis *MN*, while the point is held against a grinding wheel, causes the lip clearance to assume the shape of the cone *RST*.

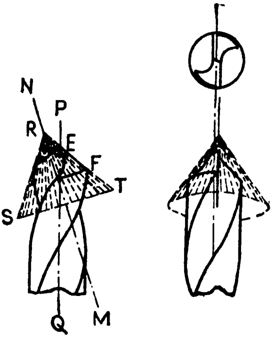
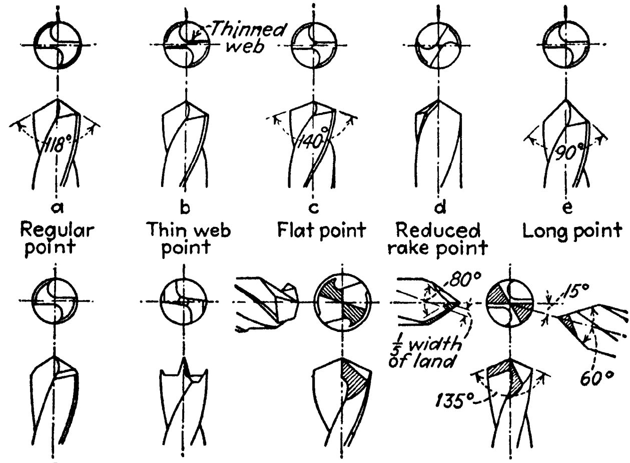


FIG. 14.—Another Method



a Regular point
b Thin web point
c Flat point
d Reduced rake point
e Long point
f Double angle point
g Spur point
h Crank shaft drill point
i Percussion drill point

FIG. 15.—Nine Useful Drill Points

KINDS OF DRILL POINTS

Nine kinds of drill points in common use are shown in Fig. 15. All have been developed for the purpose named. A point angle of 118 degrees included, or 59 degrees on a side, has been standardized for general work. This point works well in most grades of carbon and alloy steels.

The thinned web point is used when the drill has become so shortened by use that the web is too thick for economical drilling. The thinning is done on a round-faced wheel. Care must be taken to see that the web remains central. Thinning of the web reduces the thrust load on the drill point.

The flat point is often of advantage in drilling hard or tough materials. An angle of about 140 degrees included is used. For drilling manganese rails this point is often used with a drill length about one-half the regular. A point having an included angle of 125 to 130 degrees is used to drill heat-treated steels, such as drop forgings, etc., having Brinell hardness of 228 and higher.

The *reduced rake* point is used also for drilling hard materials. It is made by grinding off the sharp angles of the cutting edges to form a rake at the immediate point of 0 degree. It is also used in drilling soft materials like brass, where the regular point has a tendency to "hog in" or "grab."

The long point is used in drilling wood, bakelite, hard rubber, and fiber. It is also recommended for materials like very soft cast iron. For molded plastics some use 60 degrees with wide, polished flutes.

The double-angle point has great endurance for fast drilling of cast iron and in very hard chilled iron where excessive wear on the corners of normal points occurs. Beveling the corner also helps eliminate the revolution marks left by the drill in a hole. Some claim that beveling the corner adds 200 to 300 per cent to the life of the drill on some jobs.

The spur point is well adapted to machine drilling of wood and has been used for years on carpenter's auger bits and the like. Its advantage lies in the center prong, which locates and guides the drill, and in the two peripheral spurs, which cut the sides of the hole true with a knifelike cut.

The crankshaft, or notched, point is most often used on special crankshaft drills. These drills have a very heavy web and are long in relation to their diameters. They are used in the automotive field for drilling oil holes in crankshafts and connecting rods. The point is produced by notching off the heels on a sharp-cornered wheel.

The percussion point has been developed and patented for use on a special drill for stone, concrete, or brick. It is much more efficient than a star drill and can be used by hand, in an electric drill, or in an air hammer. The point is produced by grinding on the flat side of a wheel.

DRILLING SPEEDS AND FEEDS

The following recommended speeds and feeds should be considered as guides only, owing to the variations in materials, methods, and other operating conditions. The correct speeds and feeds must be determined by sound judgment for each particular case.

Feeds are governed by the size of the drill and the material drilled. The general rule is to use a feed of 0.001 to 0.002 inch per revolution for drills smaller than $\frac{1}{8}$ inch; 0.002 to 0.004 inch for drills $\frac{1}{8}$ to $\frac{1}{4}$ inch; 0.004 to 0.007 inch for drills $\frac{1}{4}$ to $\frac{1}{2}$ inch; 0.007 to 0.015 inch for drills $\frac{1}{2}$ to 1 inch; and 0.015 to 0.025 inch for drills larger than 1 inch. Alloy and hard steels should generally be drilled at a lighter feed than given above, while cast iron, brass, and aluminum may usually be drilled with a heavier feed.

A drill split up the web is evidence of too much feed or insufficient lip clearance at the center due to improper grinding. The rapid wearing away of the extreme outer corners of the cutting edges indicates that the speed is too high. The best results will be obtained when the effect of the work on the tool is somewhere between the above conditions. A drill chipping or breaking out at the cutting edges indicates that either the feed is too heavy or the drill has been ground with too much lip clearance. Drill troubles are tabulated on page 128.

TABLE 1.—SUGGESTED SPEEDS FOR HIGH-SPEED DRILLS

	SPEED IN FEET PER MINUTE
Mild machinery steel, 0.2 to 0.3 % carbon	80 to 110
Steel, 0.4 to 0.5 % carbon	70 to 80
Tool steel, 1.2 % carbon	50 to 60
Steel forgings	50 to 60
Alloy steel	50 to 70
Stainless steel	30 to 40
Soft cast iron	100 to 150
Hard chilled cast iron	70 to 100
Malleable iron	80 to 90
Ordinary brass and bronze	200 to 300
High-tensile bronze	70 to 150
Monel metal	40 to 50
Slate, marble, and stone	15 to 25
Aluminum and its alloys	200 to 300
Magnesium and its alloys	250 to 400
Bakelite	100 to 150
Wood	300 to 400

Carbon drills should be run at speeds of from 40 to 50 per cent of those given above.

LUBRICANTS OR CUTTING COMPOUNDS

To maintain the recommended speeds and feeds it will be necessary to use some good cutting compound. The following are recommended in the order named:

Hard and refractory steel—turpentine, kerosene, soluble oil.

Soft steel and wrought iron—lard oil, soluble oil.

Malleable iron—soda water.

Brass—dry.

Aluminum and soft alloys—kerosene, soda water.

Cast iron—dry or with a jet of compressed air for a cooling medium.

The above recommendations for lubricants apply equally well to carbon or high-speed drills.

A drill tempered to give maximum results drilling hard steel might be too brittle to work well in softer and tougher materials. The commercial twist drill is tempered for either hard or soft material. Variations in the hardness of the material drilled should, of course, be met by the skilled operator with changes in the speed and feed.

Insufficient speed in drilling small holes with hand feed greatly increases the risk of breakage, especially at the moment the point of the drill is breaking through the farther side of the work. This is due to the operator's inability correctly to gage the feed when the drills are running too slow.

High speeds and light feeds are especially recommended for automatic machines where holes do not exceed four diameters of the drill in depth. For holes deeper than four diameters an oil hole or oil-tube drill will often be found advantageous.

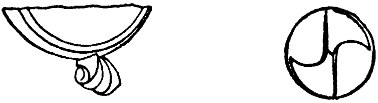


FIG. 16 FIG. 17

FIGS. 16 and 17.—Thinning the Web

Nothing will "check" a high-speed drill quicker than to turn a stream of cold water on it after it has become heated working in a hole. It is equally bad to plunge it in cold water after the point has been heated in grinding. The small checks or cracks resulting from the above practice will eventually chip out and cause rapid wear or breakage.

Drills that are properly hardened and pointed and run at moderate speeds and feeds are often condemned on account of breakage when the trouble rightly should be charged to the drilling machine. If there is any spring or play between the upper part of the machine and the table, the drill will not begin to cut until the feed pressure has taken this up, after which the feed will be practically constant until the point of the drill breaks through. As this happens, the resistance to the penetration of the drill is abruptly reduced and it "hogs in." This causes a great increase in torsional strain which frequently breaks the drill.

Any movement of the table with reference to the upper part of the machine during the drilling of a hole throws the spindle out of alignment with the hole and bends or cramps the drill, which often causes it to break.

Maximum results as far as ease of penetration and wear are concerned may best be obtained by thinning the web as the drill is worn back. This operation may be done in several ways Figure 16 illustrates the method commonly used. In this case the thinning is done with a round-faced emery wheel. The results obtained are shown in Fig. 17.

DRILLING TROUBLES, CAUSES AND REMEDIES

Symptoms	Probable Cause	Remedy
Breaking of drill	Spring or back lash in press or work Too little lip clearance Too low speed in proportion to the feed Flutes full of chips Dull drill	Test press and work for rigidity and alignment Regrind properly Increase speed or decrease feed Sharpen drill
Breaking down of outer corners of cutting edges	Material being drilled has hard spots, scale, or sand inclusions Too much speed Improper cutting compound No lubricant at point of drill	Reduce speed Use proper cutting compound and correct application
Breaking of drill when drilling brass or wood	Chips clog up flutes	Increase speed Use drills designed for these materials
Broken tang	Imperfect fit of taper shank in the socket—due to nicks, dirt, burrs or worn-out socket	Get a new socket or ream old one to prevent recurrence
Chipping of margin	Oversize jig bushing	Use proper size bushing
Chipping of lip or cutting edges	Too much feed Too much lip clearance	Reduce feed—see table on page 126. Regrind properly
Chipping or checking of a high-speed drill	Heated and cooled too quickly while grinding or while drilling Too much feed	Warm slowly before using Do not throw cold water on hot drill while grinding or drilling Reduce feed
Change in character of chips while drilling	Change in condition of the drill such as chipping of cutting edge, and dulling.	Regrind drill properly
Hole too large	Unequal angle or length of the cutting edges—or both. Loose spindle	Regrind properly Test spindle for rigidity
Only one lip cutting or one large, one small chip	Unequal length or angle of cutting lips or both	Regrind drill properly
Splitting up center	Too little lip clearance Too much feed	Regrind with proper lip clearance Reduce feed
Rough hole	Dull or improperly ground drill. Lack of lubricant or wrong lubricant Improper set-up Too much feed	Regrind properly Lubricate or change lubricant Reduce feed

TYPES OF SPECIAL TWIST DRILLS AND THEIR USES

While the ordinary twist drill can handle the great majority of drilling jobs, special circumstances may require the designing of a new type of drill. Some of these special tools are listed below and shown in Fig. 18.

Three and Four-Fluted Drills.—Not adapted to drill holes from the solid but used to enlarge cored, punched, or previously drilled holes. Sometimes used in place of roughing reamers.

Combination Tools.—Any combination of rotary cutting tools, such as drill and reamer; drill and countersink; step drill of several diameters; drill, reamer, countersink, etc.

Shell Drills.—Used for the same purpose as three or four-fluted drills. Made with tapered hole and fit on an arbor. One size of arbor will hold a large range of shell drills.

Oil-Hole Drills.—Used mostly in screw-machine or turret-lathe work for drilling deep holes. Have one or two oil holes running from the shank to the cutting point, and oil may be forced through these holes for lubrication.

Oil-Tube Drills.—Have oil tubes sunk in grooves cut in the lands of the drill instead of oil holes.

Straight Fluted Drill.—These have two straight flutes running parallel to the axis. They are well adapted for brass, copper, or other soft metals, as they will not run ahead or grab. Formerly called Farmer drill.

Dual-Cut Drills.—Two- or three-step combination drills with the lands of the small diameter ground to size for the full length of the flutes.

High-Helix Drills.—Has a helix angle of about 40 degrees. Developed for the drilling of slate and marble. Also useful in drilling deep holes in aluminum, magnesium, wood, copper, and fiber.

Bakelite Drills.—Has a wide, polished flute adapted for use in bakelite, fiber, and hard rubber. Generally made of high-speed steel to resist abrasion.

Stove-Burner Drill.—Has a very short flute for great strength. Well adapted for drilling short holes in quantity.

Brass Drills.—Usually carbon steel with special shape. Superior to regular drills for brass work. Also satisfactory for magnesium alloys.

Crankshaft Drills.—Specially designed for oil-hole drilling in crankshafts and connecting rods. Do not often exceed 60 diameters in length. Have heavy webs and must be pointed as shown in Fig. 15. Drill must be withdrawn frequently in deep-hole drilling.

Flat-Track Drills.—Forged flat and have a special point milled on the end.

Manganese Drills.—Developed for drilling work-hardening manganese steels. They are short and stubby with a heavy cross section and thick web. Slow speed and a heavy power feed are recommended.

Bonding Drills.—Designed and tempered for drilling holes for bonding wires in track-circuit signal work. Shorter and heavier than regular drills.

Bobbin Bit.—Developed for the drilling of deep holes in wood. Its chip-clearing ability makes it useful in drilling celluloid.

Spoon Bit.—For drilling stacked layers of paper, cardboard, or thin wood. Has a crescent-moon section with sharp edges. They remove a central core of the material.

Tube Drill.—For drilling holes in paper or cardboard. Similar to spoon bit in action. The hollow tube with sharpened ends removes a solid core.

Router Bits.—Made in an endless variety of styles and shapes. Widely used in wood-carving and engraving machines.

Glass Drills.—At least three ways of drilling holes in glass are in use. In one method a three-cornered file has its point ground off smooth and is rotated in a drill press. Another method is to use a copper tube of the correct diameter and apply plenty of abrasive powder to its cutting end. A solid copper rod may be substituted for the tube but is much slower. Liberal application of turpentine must be made in all cases. See Fig. 18.

Flat Drills.—The flat drill is well adapted for very small sizes. They are sold in diameters as small as 0.002 inch. These tools are mostly used by jewelers and watchmakers, in sizes smaller than 0.010″.

Hollow Drill.—Especially adapted for horizontal screw machine use in drilling deep holes, such as gun barrels. The drill is provided with a threaded shank. A hole through this shank runs into the flutes. The drill is screwed

TABLE 2.—CUTTING SPEEDS

Number Size Drills

Ft. per Minute	30	40	50	60	70	80	90	100	110	120	130	140	150
No. Size	Revolutions per Minute												
1	503	670	838	1,005	1,173	1,340	1,508	1,675	1,843	2,010	2,179	2,346	2,513
2	518	691	864	1,037	1,210	1,382	1,555	1,728	1,901	2,074	2,247	2,420	2,593
3	538	717	897	1,076	1,255	1,434	1,614	1,793	1,974	2,152	2,331	2,511	2,690
4	548	731	914	1,097	1,280	1,462	1,645	1,828	2,010	2,193	2,376	2,560	2,741
5	558	744	930	1,115	1,301	1,487	1,673	1,859	2,045	2,230	2,416	2,602	2,788
6	562	749	936	1,123	1,310	1,498	1,685	1,872	2,060	2,247	2,434	2,621	2,809
7	570	760	950	1,140	1,330	1,520	1,710	1,900	2,090	2,281	2,470	2,660	2,850
8	576	768	960	1,151	1,343	1,535	1,727	1,919	2.111	2,303	2,495	2,687	2,879
9	585	780	975	1,169	1,364	1,559	1,754	1,949	2,144	2,339	2,534	2,728	2,923
10	592	790	987	1,184	1,382	1,579	1,777	1,974	2,171	2,369	2,566	2,764	2,961
12	606	808	1,010	1,213	1,415	1,617	1,819	2,021	2,223	2,425	2,627	2,829	3,032
14	630	840	1,050	1,259	1,469	1,679	1,889	2,099	2,309	2,518	2,728	2,938	3,148
16	647	863	1,079	1,295	1,511	1,726	1,942	2,158	2,374	2,590	2,806	3,021	3,237
18	678	904	1,130	1,356	1,582	1,808	2,034	2,260	2,479	2,704	2,930	3,155	3,380
20	712	949	1,186	1,423	1,660	1,898	2,135	2,372	2,610	2,847	3,084	3,322	3,559
22	730	973	1,217	1,460	1,703	1,946	2,190	2,433	2,676	2,920	3,164	3,406	3,649
24	754	1,005	1,257	1,508	1,759	2,010	2,262	2,513	2,764	3,016	3,267	3,518	3,769
26	779	1,039	1,299	1,559	1,819	2,078	2,338	2,598	2,858	3,118	3,378	3,638	3,898
28	816	1,088	1,360	1,631	1,903	2,175	2,447	2,719	2,990	3,262	3,534	3,806	4,078
30	892	1,189	1,487	1,784	2,081	2,378	2,676	2,973	3,270	3,567	3,864	4,162	4,459
32	988	1,317	1,647	1,976	2,305	2,634	2,964	3,293	3,622	3,951	4,281	4,610	4,939
34	1,032	1,376	1,721	2,065	2,409	2,753	3,097	3,442	3,785	4,129	4,474	4,818	5,162
36	1,076	1,435	1,794	2,152	2,511	2,870	3,228	3,587	3,945	4,304	4,663	5,021	5,380
38	1,129	1,505	1,882	2,258	2,634	3,010	3,387	3,763	4,140	4,516	4.892	5,269	5,645

40	1,169	1,559	1,949	2,339	2,729	3,118	3,508	3,898	4,287	4,677	5,067	5,457	5,846
42	1,226	1,634	2,043	2,451	2,860	3,268	3,677	4,085	4,494	4,902	5,311	5,719	6,128
44	1,333	1,777	2,221	2,665	3,109	3,554	3,999	4,442	4,886	5,330	5,774	6.218	6,662
46	1,415	1,886	2,358	2,830	3,301	3,773	4,244	4,716	5,187	5,659	6,130	6,602	7,074
48	1,508	2,010	2,513	3,016	3,518	4,021	4,523	5,026	5,528	6,031	6,534	7,036	7,539
50	1,637	2,183	2,729	3,274	3,820	4,366	4,911	5,457	6,002	6,548	7,094	7,640	8,185
52	1,805	2,406	3,008	3,609	4,211	4,812	5,414	6,015	6,619	7,218	7,820	8,421	9,023
54	2,084	2,778	3,473	4,167	4,862	5,556	6,251	6,945	7,639	8,334	9,028	9,723	10,417
56	2,465	3,286	4,108	4,929	5,751	6,572	7,394	8,215	9,036	9,857	10,678	11,500	12,322
58	2,729	3,637	4,547	5,456	6,367	7,275	8,186	9,095	10,004	10,913	11,823	12,732	13,642
60	2,865	3,820	4,775	5,729	6,684	7,639	8,594	9,549	10,504	11,459	12,414	13,369	14,324
62	3,015	4,020	5,025	6,030	7,035	8,040	9,045	10,050	11,057	12,060	13,068	14,073	15,078
64	3,183	4,244	5,305	6,366	7,427	8,488	9,549	10,610	11,671	12,732	13,793	14,854	15,915
66	3,474	4,632	5,790	6,948	8,106	9,264	10,422	11,580	12,732	13,890	15,047	16,205	17,362
68	3,696	4,928	6,160	7,392	8,624	9,856	11,088	12,320	13,554	14,786	16,018	17,250	18,482
70	4,091	5,456	6,820	8,184	9.548	10,912	12,276	13,640	15,006	16,370	17,734	19,099	20,463
72	4,584	6,112	7,640	9,168	10,696	12,224	13,752	15,280	16,807	18,335	19,863	21,390	22,918
74	5,106	6,808	8,510	10,212	11,914	13,616	15,318	17,020	18,674	20,372	22,069	23,767	25,465
76	5,730	7,640	9,550	11,460	13,370	15,280	17,190	19,100	21,008	22,918	24,828	26,738	28,648
78	7,161	9,548	11,935	14,322	16,709	19,096	21,483	23,870	26,260	28,648	31,035	33,422	35,810
80	8,490	11,320	14,150	16,980	19,810	22,640	25,470	28,300	31,123	33,953	36,782	39,612	42,441

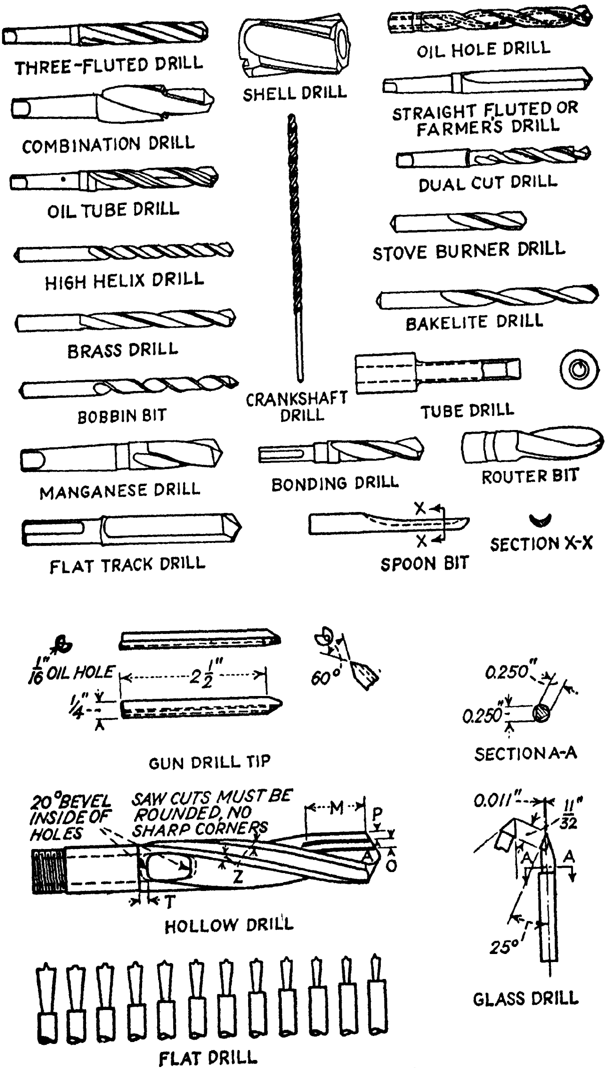


FIG. 18.—Drills for Various Purposes

TABLE 3.—CUTTING SPEEDS
Fraction and Letter Size Drills

Ft. per Min.	30	40	50	60	70	80	90	100	110	120	130	140	150
Diameter, In.	Revolutions per Minute												
1/16	1,833	2,445	3,056	3,667	4,278	4,889	5,500	6,111	6,722	7,334	7,945	8,556	9,167
1/8	917	1,222	1,528	1,833	2,139	2,445	2,750	3,056	3,361	3,667	3,973	4,278	4,584
3/16	611	815	1,019	1,222	1,426	1,630	1,833	2,037	2,241	2,445	2,648	2,852	3,056
1/4	458	611	764	917	1,070	1,222	1,375	1,528	1,681	1,833	1,986	2,139	2,292
5/16	367	489	611	733	856	978	1,100	1,222	1,345	1,467	1,589	1,711	1,833
3/8	306	407	509	611	713	815	917	1,019	1,120	1,222	1,324	1,426	1,528
7/16	262	349	437	524	611	698	786	873	960	1,048	1,135	1,222	1,310
1/2	229	306	382	458	535	611	688	764	840	917	993	1,070	1,146
5/8	183	244	306	367	428	489	550	611	672	733	794	856	917
3/4	153	203	255	306	357	407	458	509	560	611	662	713	764
7/8	131	175	218	262	306	349	393	436	480	524	568	611	655
1	115	153	191	229	267	306	344	382	420	458	497	535	573
1 1/8	102	136	170	204	238	272	306	340	373	407	441	475	509
1 1/4	92	122	153	183	214	244	275	306	336	367	397	428	458
1 3/8	83	111	139	167	194	222	250	278	306	333	361	389	417
1 1/2	76	102	127	153	178	204	229	255	280	306	331	357	382
1 5/8	70	94	117	141	165	188	212	235	259	282	306	329	353
1 3/4	65	87	109	131	153	175	196	218	240	262	284	306	327
1 7/8	61	81	102	122	143	163	183	204	224	244	265	285	306
2	57	76	95	115	134	153	172	191	210	229	248	267	287
2 1/4	51	68	85	102	119	136	153	170	187	204	221	238	255
2 1/2	46	61	76	92	107	122	137	153	168	183	199	214	229
2 3/4	42	56	69	83	97	111	125	139	153	167	181	194	208
3	38	51	64	70	89	102	115	127	140	153	166	178	191
A	491	654	818	982	1,145	1,309	1,472	1,636	1,796	1,959	2,122	2,285	2,448
B	484	642	803	963	1,124	1,284	1,445	1,605	1,765	1,926	2,086	2,247	2,407
C	473	631	789	947	1,105	1,262	1,420	1,578	1,736	1,894	2,052	2,210	2,368
D	467	622	778	934	1,089	1,245	1,400	1,556	1,708	1,863	2,018	2,174	2,329
E	458	611	764	917	1,070	1,222	1,375	1,528	1,681	1,834	1,968	2,139	2,292
F	446	594	743	892	1,040	1,189	1,337	1,486	1,635	1,784	1,932	2,081	2,229
G	440	585	732	878	1,024	1,170	1,317	1,463	1,610	1,756	1,903	2,049	2,195
H	430	574	718	862	1,005	1,149	1,292	1,436	1,580	1,723	1,867	2,010	2,154
I	421	562	702	842	983	1,123	1,264	1,404	1,545	1,685	1,826	1,966	2,106
J	414	552	690	827	965	1,103	1,241	1,379	1,517	1,655	1,793	1,930	2,068
K	408	544	680	815	951	1,087	1,223	1,359	1,495	1,631	1,767	1,903	2,039
L	395	527	659	790	922	1,054	1,185	1,317	1,449	1,581	1,712	1,844	1,976
M	389	518	648	777	907	1,036	1,166	1,295	1,424	1,554	1,683	1,813	1,942
N	380	506	633	759	886	1,012	1,139	1,265	1,391	1,518	1,644	1,771	1,897
O	363	484	605	725	846	967	1,088	1,209	1,330	1,450	1,571	1,692	1,813
P	355	473	592	710	828	946	1,065	1,183	1,301	1,419	1,537	1,657	1,774
Q	345	460	575	690	805	920	1,035	1,150	1,266	1,384	1,496	1,611	1,726
R	338	451	564	676	789	902	1,014	1,127	1,239	1,355	1,465	1,577	1,690
S	329	439	549	659	769	878	988	1,098	1,207	1,317	1,427	1,537	1,646
T	320	426	533	640	746	853	959	1,066	1,173	1,280	1,387	1,494	1,600
U	311	415	519	623	727	830	934	1,038	1,142	1,246	1,349	1,453	1,557
V	304	405	507	608	709	810	912	1,013	1,114	1,219	1,317	1,418	1,520
W	297	396	495	594	693	792	891	989	1,088	1,188	1,286	1,385	1,484
X	289	385	481	576	672	769	865	962	1,058	1,155	1,251	1,347	1,443
Y	284	378	473	567	662	756	851	945	1,040	1,135	1,229	1,324	1,418
Z	277	370	462	555	647	740	832	925	1,017	1,110	1,202	1,295	1,387

TABLE 4.—SPEEDS AND FEEDS FOR DRILLS OF HIGH-SPEED STEEL IN VARIOUS METALS WITH A SUITABLE COOLANT

Size of Drill	Feed per Revolution	Bronze, Brass	Alloy-Steel Drop-forging	Cast Iron	Tool and Carbon-steel Drop-forgings	Mild Steel	Malleable Iron	Cast Steel	Hard Cast Iron
t. per Min.		300	50	140	60	120	90	40	80
In.	In.	R.P.M.							
1/16	0.0030	18,320	3,056	8,554	3,667	7,328	5,500	2,445	4,889
3/32	0.0035	12,212	2,038	5,702	2,442	4,884	3,666	1,628	3,258
1/8	0.0040	9,160	1,528	4,278	1,833	3,667	2,750	1,222	2,445
5/32	0.0045	7,328	1,221	3,420	1,465	2,934	2,198	976	1,954
3/16	0.0050	6,106	1,019	2,852	1,222	2,445	1,833	815	1,630
7/32	0.0055	5,234	872	2,444	1,047	2,094	1,570	698	1,396
1/4	0.0060	4,575	764	2,139	917	1,833	1,375	611	1,222
9/32	0.0065	4,071	678	1,900	814	1,628	1,222	542	1,084
5/16	0.0070	3,660	611	1,711	733	1,467	1,100	489	978
11/32	0.0075	3,330	555	1,554	666	1,332	1,000	444	888
3/8	0.0080	3,050	509	1,426	611	1,222	917	407	815
13/32	0.0085	2,818	469	1,316	563	1,126	846	376	752
7/16	0.0090	2,614	437	1,222	524	1,048	786	349	698
15/32	0.0095	2,442	407	1,140	488	976	732	326	652
1/2	0.0100	2,287	382	1,070	458	917	688	306	611
9/16	0.0105	2,035	339	950	407	814	611	271	543
5/8	0.0110	1,830	306	856	367	733	550	244	489
11/16	0.0115	1,665	277	777	333	666	500	222	444
3/4	0.0120	1,525	255	713	306	611	458	204	407
13/16	0.0125	1,409	234	658	281	562	423	188	376
7/8	0.0130	1,307	218	611	262	524	393	175	349
15/16	0.0135	1,221	203	570	244	488	366	163	326
	0.0140	1,143	191	535	229	458	344	153	306
[illegible]	0.0150	1,017	170	475	204	407	306	136	272
[illegible]	0 0160	915	153	428	183	367	275	122	244
[illegible]	0.0160	833	139	389	167	333	250	111	222
[illegible]	0.0160	762	127	357	153	306	229	102	204
[illegible]	0.0160	705	118	329	141	282	212	94	188
[illegible]	0.0160	654	109	306	131	262	196	87	175
[illegible]	0.0160	610	102	285	122	244	183	81	163
	0.0160	571	95	267	115	229	172	76	153

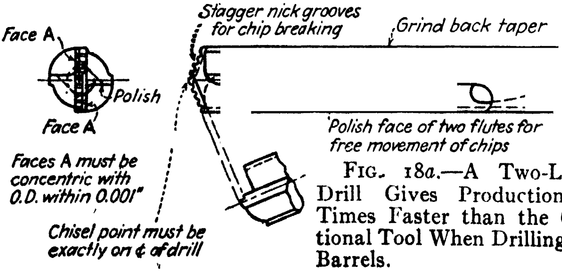

Face A
Polish
Face A
Faces A must be concentric with O.D. within 0.001"
Chisel point must be exactly on ¢ of drill
Stagger nick grooves for chip breaking
Grind back taper
Polish face of two flutes for free movement of chips

FIG. 18a.—A Two-Lip Gun Drill Gives Production Three Times Faster than the Conventional Tool When Drilling Forged Barrels.

to the end of a substantial pipe. The work is generally rotated and lubricant is forced through the pipe to the cutting lips. Not made in sizes smaller than 3/8 inch.

Gun-Drill Tip.—The gun-drill tip is used almost exclusively for drilling long small-diameter holes, such as rifle barrels. The tool is fastened to the end of a long hollow rod, and the work is rotated. Lubricant is forced through the rod to the drill tip. The tip is of round section with a deep V groove milled parallel to its axis.

TABLE 5.—THRUST LOADS ON TWIST DRILLS*

Diameter of Drill, Inches	Feed per Revolution	Thrust, in Pounds	
		Cast Iron	Steel
1/8	0.004		130
5/32	0.0045		185
3/16	0.005		245
1/4	0.006		380
3/8	0.008		550
1/2	0.010	200	750
5/8	0.011	275	1000
3/4	0.012	325	1275
7/8	0.013	400	1590
1	0.014	500	1910
1 1/4	0.016	700	2650
1 1/2	0.016	850	3200

* Carl J. Oxford, National Twist Drill & Tool Co.

TABLE 6.—HORSE-POWER REQUIRED FOR DRILLING*

Diameter of Drill, Inches	Feed per Revolution, Inches	Cast Iron		Steel	
		100 Revolutions per Minute	100 Surface Feet per Minute	100 Revolutions per Minute	60 Surface Feet per Minute
1/8	0.004			0.010	0.180
5/32	0.0045			0.017	0.240
3/16	0.005			0.026	0.310
1/4	0.006			0.050	0.440
3/8	0.008			0.23	1.28
1/2	0.010	0.26	1.60	0.34	1.65
5/8	0.011	0.40	2.30	0.52	1.90
3/4	0.012	0.59	2.90	0.77	2.35
7/8	0.013	0.80	3.44	1.06	2.78
1	0.014	1.06	4.02	1.40	3.20
1 1/4	0.016	1.83	5.58	2.42	4.43
1 1/2	0.016	2.44	6.10	3.22	5.00

* Carl J. Oxford, National Twist Drill & Tool Co.

SMALL FLAT DRILLS

Flat drills are used for very small holes such as 0.002 in. One maker, the Grobet File Corporation of America lists them as follows:

GROBET HIGH-SPEED STEEL FLAT DRILLS

Length Over All, in Inches	Diameter Shank, in Inches	Diameter Cutting Blade, in Inches
[illegible]	0.040	0.002
[illegible]	0.040	0.0025
[illegible]	0.040	0.003
[illegible]	0.040	0.0035
[illegible]	0.040	0.004
[illegible]	0.040	0.0045 to 0.005
[illegible]	0.040	0.0055 to 0.008
[illegible]	0.040	0.0085 to 0.014
[illegible]	0.040	0.0145 to 0.020
[illegible]	0.040	0.0205 to 0.025
[illegible]	0.040	0.0255 to 0.030
[illegible]	0.060	0.0305 to 0.040
[illegible]	0.060	0.0405 to 0.055
[illegible]	0.070	0.0555 to 0.065
1	0.083	0.0655 to 0.080

The length of the drill blade is about five times its diameter.

To get the best results, the cutting and clearance angles of the drills vary according to the metal in which the holes are to be drilled. It is important to specify the kind of material on which the drills will be used. The speed at which the drills can be used varies according to the hardness of the metal. On soft metal, like brass, a speed of 20,000 revolutions per minute is possible, but on very hard steel, such as nickel-chrome steel, the maximum speed is 2,000 revolutions per minute. However, when extremely small drills, 0.002 to 0.010 inch, are used, the speed should be reduced even further.

Drilling Armor Plate

Use included point angle 135 to 140 deg.; clearance angle of 6 to 9 deg. at periphery; chisel point angle of 115 to 125 deg. For shallow holes use 40 to 50 surface feet per minute, for deeper holes reduce speeds. Use feeds about 15 to 25 per cent less than for ordinary materials.

EXAMPLE.—A $\frac{15}{16}$-inch drill at 40 surface feet per minute with feed of 0.010 inch per revolution. This drill should run 163 revolutions per minute. For 50 feet per minute, the speed would be 203 revolutions per minute. See the table on page 134. For coolant use rich mixture (8 or 10 to 1) of soluble oil or good sulphurized cutting oil. If one side is harder than the other, drill the hard side first.

Small Twist Drills

Twist drills are made from 0.015 to 0.040 inch in diameter. Being long in proportion to their diameter, they are subject to deflection and must be handled very carefully. The web, or center section, is much thicker in proportion to diameter than that of larger drills. This reduces chip space and requires more feeding pressure. They frequently drill comparatively deep holes and must be cleared more often than larger drills.

Speeds and feeds must be carefully selected. The drills must be guided to minimize deflection and must be kept sharp.

TABLE 7.—DIAMETERS AND AREAS OF SMALL DRILLS
Number, Letter, Metric, and Fractional Drills in Order of Size

Number	Letter	Metric, Mm.	Fraction	Diameter, In.	Area, Sq. In.	Number	Letter	Metric, Mm.	Fraction	Diameter, In.	Area, Sq. In.
		0.100		0.003900	0.0000119			1.450		0.057000	0.0025440
		0.150		0.005900	0.0000273			1.500		0.059000	0.0027390
		0.200		0.007800	0.0000477	53				0.059500	0.0027810
		0.250		0.009800	0.0000753			1.550		0.061000	0.0029210
		0.300		0.011800	0.0001091				1/16	0.062500	0.0030680
80				0.013500	0.0001429			1.600		0.062990	0.0031160
		0.350		0.013700	0.0001468	52				0.063500	0.0031670
79				0.014500	0.0001650			1.650		0.064900	0.0033060
			1/64	0.015620	0.0001920			1.700		0.066920	0.0035180
		0.400		0.015740	0.0001950	51				0.067000	0.0035260
78				0.016000	0.0002010			1.750		0.068800	0.0037140
		0.450		0.017700	0.0002450	50				0.070000	0.0038480
77				0.018000	0.0002540			1.800		0.070860	0.0039440
		0.500		0.019680	0.0003040			1.850		0.072800	0.0041620
76				0.020000	0.0003140	49				0.073000	0.0041850
75				0.021000	0.0003460			1.900		0.074800	0.0043940
		0.550		0.021600	0.0003650	48				0.076000	0.0045360
74				0.022500	0.0003980			1.950		0.076700	0.0046180
		0.600		0.023620	0.0004380				5/64	0.078120	0.0047940
73				0.024000	0.0004520	47				0.078500	0.0048400
72				0.025000	0.0004910			2.000		0.078740	0.0048690
		0.650		0.025500	0.0005100			2.050		0.080700	0.0051120
71				0.026000	0.0005310	46				0.081000	0.0051530
		0.700		0.027560	0.0005970	45				0.082000	0.0052810
70				0.028000	0.0006160			2.100		0.082670	0.0053690
69				0.029250	0.0006720			2.150		0.084600	0.0056150
		0.750		0.029500	0.0006830	44				0.086000	0.0058090
68				0.031000	0.0007550			2.200		0.086610	0.0058920
			1/32	0.031250	0.0007670			2.250		0.088500	0.0061490
		0.800		0.031490	0.0007790	43				0.089000	0.0062210
67				0.032000	0.0008040			2.300		0.090550	0.0064400
66				0.033000	0.0008550			2.35		0.092500	0.0067150
		0.850		0.033400	0.0008710	42				0.093500	0.0068600
65				0.035000	0.0009620				3/32	0.093750	0.0069030
		0.900		0.035430	0.0009860			2.400		0.094480	0.0070120
64				0.036000	0.0010180	41				0.096000	0.0072380
63				0.037000	0.0010750			2.45		0.096400	0.0072960
		0.950		0.037400	0.0010910	40				0.098000	0.0075430
62				0.038000	0.0011340			2.50		0.098420	0.0076090
61				0.039000	0.0011950	39				0.099500	0.0077760
		1.000		0.039370	0.0012170	38				0.101500	0.0080910
60				0.040000	0.0012570			2.60		0.102360	0.0082290
59				0.041000	0.0013200	37				0.104000	0.0084900
		0.105		0.041300	0.0013510			2.70		0.106300	0.0088750
58				0.042000	0.0013850	36				0.106500	0.0089080
57				0.043000	0.0014520			2.75		0.108200	0.0091890
		1.100		0.043300	0.0014730				7/64	0.109370	0.0093960
		1.150		0.045200	0.0016100	35				0.110000	0.0095030
56				0.046500	0.0016980			2.80		0.110240	0.0095440
			3/64	0.046870	0.0017260	34				0.111000	0.0096770
		1.200		0.047240	0.0017530	33				0.113000	0.0100290
		1.250		0.049200	0.0019000			2.90		0.114170	0.0102380
		1.300		0.051181	0.0020570	32				0.116000	0.0105680
55				0.052000	0.0021240			3.00		0.118110	0.0109590
		1.350		0.053100	0.0022060	31				0.120000	0.0113100
54				0.055000	0.0023760			3.10		0.122050	0.0116900
		1.400		0.055100	0.0023860				1/8	0.125000	0.0122720

TABLE 7.—DIAMETERS AND AREAS OF SMALL DRILLS.—*Continued*
Number, Letter, Metric, and Fractional Drills in Order of Size

Number	Letter	Metric, Mm.	Fraction	Diameter In.	Area, Sq. In.	Number	Letter	Metric, Mm.	Fraction	Diameter In.	Area, Sq. In.
		3.20		0.125980	0.0124660	4				0.209000	0.0343070
		3.25		0.127900	0.0128020			5.400		0.212600	0.0354990
30				0.128500	0.0129690	3				0.213000	0.0356330
		3.30		0.129920	0.0132570			5.500		0.216540	0.0368250
		3.40		0.133860	0.0140730				7/32	0.218750	0.0375830
29				0.136000	0.0145270			5.600		0.220470	0.0381770
		3.50		0.137800	0.0149130	2				0 221000	0.0383600
28				0.140500	0.0155040			5.700		0.224410	0.0395520
			9/64	0.140620	0.0155310			5.750		0.226300	0.0402430
		3.60		0.141730	0.0157770	1				0.228000	0.0408280
27				0.144000	0.0162860			5.800		0.228350	0.0409520
		3.70		0.145670	0.0166660			5.900		0.232280	0.0423770
26				0.147000	0.0169720		A			0.234000	0.0430050
		3.75		0.147600	0.0171060				15/64	0.234370	0.0431410
25				0.149500	0.0175540			6.000		0.236220	0.0438250
		3.80		0.149610	0.0175790		B			0.238000	0.0444880
24				0.152000	0.0181460			6.100		0.240150	0.0452990
		3.90		0.153540	0.0185160		C			0.242000	0.0459960
23				0.154000	0.0186270			6.200		0.244100	0.0467970
			5/32	0.156250	0.0191750		D			0.246000	0.0475290
22				0.157000	0.0193590			6.250		0.246060	0.0475480
		4.00		0.157480	0.0194780			6.300		0.248030	0.0483170
21				0.159000	0.0198560		E		1/4	0.250000	0.0490870
20				0.161000	0.0203580			6.400		0.251970	0.0498630
		4.10		0.161420	0.0204640			6.500		0.255910	0.0514340
		4.2		0.165360	0.0214740		F			0.257000	0.0518750
19				0.166000	0.0216420			6.600		0.259800	0.0530280
		4.25		0.167300	0.0220560		G			0.261000	0.0535020
		4.30		0.169290	0.0225050			6.700		0.263700	0.0546480
18				0.169500	0.0225650				17/64	0.265600	0.0554120
			11/64	0.171875	0.0232020			6.750		0.265700	0.0554140
17				0.173000	0.0235060		H			0.266000	0.0555720
		4.40		0.173230	0.0235680			6.800		0.267720	0.0562910
16				0.177000	0.0246060			6.900		0.271650	0.0579590
		4.50		0.177170	0.0246520		I			0.272000	0.0581070
15				0.180000	0.0254470			7.000		0.275500	0.0596510
		4.60		0.181100	0.0257600		J			0.277000	0.0602630
14				0.182000	0.0260160			7.100		0.279500	0.0613670
13				0.185000	0.0268800		K			0.281000	0.0620160
		4.70		0.185040	0.0268920				9/32	0.281250	0.0621260
		4.75		0.187000	0.0274570			7.200		0.283470	0.0631080
			3/16	0.187500	0.0276120			7.250		0.285400	0.0639700
		4.80		0.188980	0.0280480			7.300		0.287400	0.0648740
12				0.189000	0.0280550		L			0.290000	0.0660520
11				0.191000	0.0286520			7.400		0.291330	0.0666630
		4.90		0.192910	0.0292290		M			0.295000	0.0683490
10				0.193500	0.0294070			7.500		0.295200	0.0684770
9				0.196000	0.0301720				19/64	0.296875	0.0692180
		5.00		0.196850	0.0304340			7.600		0.299220	0.0703150
8				0.199000	0.0311030		N			0.302000	0.0716310
		5.10		0.200790	0.0316640			7.700		0.303140	0.0721780
7				0.201000	0.0317310			7:750		0.305100	0.0730570
			13/64	0.203120	0.0324030			7.800		0.307090	0.0740650
6				0.204000	0.0326850			7.900		0.311020	0.0759760
		5.20		0.204730	0.0329180				5/16	0.312500	0.0766990
5				0.205500	0.0331681			8.000		0.314960	0.0779120
		5.25		0.206600	0.0335200		O			0.316000	0.0784270
		5.30		0.208600	0.0341960					0.318890	0.0798720

TABLE 7.—DIAMETERS AND AREAS OF SMALL DRILLS.—*Continued*
Number, Letter, Metric, and Fractional Drills in Order of Size

Number	Letter	Metric, Mm.	Fraction	Diameter In.	Area, Sq In.	Number	Letter	Metric, Mm.	Fraction	Diameter In.	Area, Sq. In.
		8.100		0 322830	0.0818560				35/64	0.546800	0.2341200
	P	8.200		0.323000	0.0819400			14.00		0.551100	0.2384400
		8.250		0.324800	0.0827810				9/16	0.562500	0.2485000
		8.300		0.326800	0.0838650			14.50		0.570800	0.2560400
			21/64	0.328120	0.0845580				37/64	0.578100	0.2624800
		8.400		0.330700	0.0858980			15.00		0.590500	0.2733900
	Q			0.332000	0.0865700				19/32	0.593700	0.2768800
		8.500		0.334650	0.0879550				39/64	0.609300	0.2916100
		8.600		0.338580	0.0900370			15.50		0.610200	0.2922400
	R			0.339000	0.0902590				5/8	0.625000	0.3068000
		8.700		0.342500	0.0921430			16.00		0.629900	0.3117200
			11/32	0.343700	0.0928060				41/64	0.640600	0.3223200
		8.750		0.344400	0.0929120			16.50		0.649600	0.3308100
		8.800		0.346400	0.0942740				21/32	0.656200	0.3382400
	S			0.348000	0.0951150			17.00		0.669200	0.3514200
		8.900		0.350400	0.0964280				43/64	0.671800	0.3645400
		9.000		0.354300	0.0986070				11/16	0.687500	0.3712200
	T			0.358000	0.1006600			17.50		0.688900	0.3726700
		9.100		0.358300	0.1008110				45/64	0.703100	0.3882800
			23/64	0.359300	0.1014340			18.00		0.708600	0.3943400
		9.200		0.362200	0.1030390				23/32	0.718700	0.4057400
		9.250		0.364100	0.1039860			18.50		0.728300	0.4165700
		9.300		0.366100	0.1052910				47/64	0.734300	0.4235600
	U			0.368000	0.1063620			19.00		0.748000	0.4393500
		9.400		0.370100	0.1075670				3/4	0.750000	0.4417900
		9.500		0.374020	0.1098680				49/64	0.765600	0.4587500
			3/8	0.375000	0.1104470			19.50		0.767700	0.4628300
	V			0.377000	0.1116280				25/32	0.781200	0.4793700
		9.600		0.377950	0.1121930			20.00		0.787400	0.4868600
		9.700		0.381800	0.1145430				51/64	0.796800	0.4977200
		9.750		0.383800	0.1156890			20.50		0.807000	0.5115800
		9.800		0.385800	0.1169170				13/16	0.812500	0.5184900
	W			0.386000	0.1170210			21.00		0.826700	0.5368500
		9.900		0.389800	0.1193150				53/64	0.828100	0.5386100
			25/64	0.390620	0.1198440				27/32	0.843700	0.5591400
		10.00		0.393700	0.1217380			21.50		0.846400	0.5626600
	X			0.397000	0.1237860				55/64	0.859300	0.5799200
	Y			0.404000	0.1281900			22.00		0.866100	0.5892000
			13/32	0.406200	0.1296220				7/8	0.875000	0.6013200
	Z			0.413000	0.1339650			22.50		0.885800	0.6162900
		10.50		0.413300	0.1342000				57/64	0.890600	0.6229700
			27/64	0.421800	0.1397200			23.00		0.905500	0.6400700
		11.00		0.433000	0.1471800				29/32	0.906200	0.6450400
			7/16	0.437500	0.1503300				59/64	0.921800	0.6674600
		11.50		0.452700	0.1607600			23.50		0.925100	0.6722200
			29/64	0.453100	0.1612400				15/16	0.937500	0.6902900
			15/32	0.468700	0.1725700			24.00		0.944800	0.7011900
		12 00		0.472400	0.1749000				61/64	0.953100	0.7150200
			31/64	0.484300	0.1842500			24.50		0.964500	0.7297900
		12.50		0.492100	0.1901400				31/32	0.968700	0.7370800
			1/2	0.500000	0.1963500			25.00		0.984200	0.7614400
		13.00		0.511800	0.2050700				63/64	0.998430	0.7634500
			33/64	0.515600	0.2087500				1.0	1.000000	0.7854000
			17/32	0.531200	0.2216600			25.50		1.003000	0.7915200
		13.50		0.531400	0.2217900						

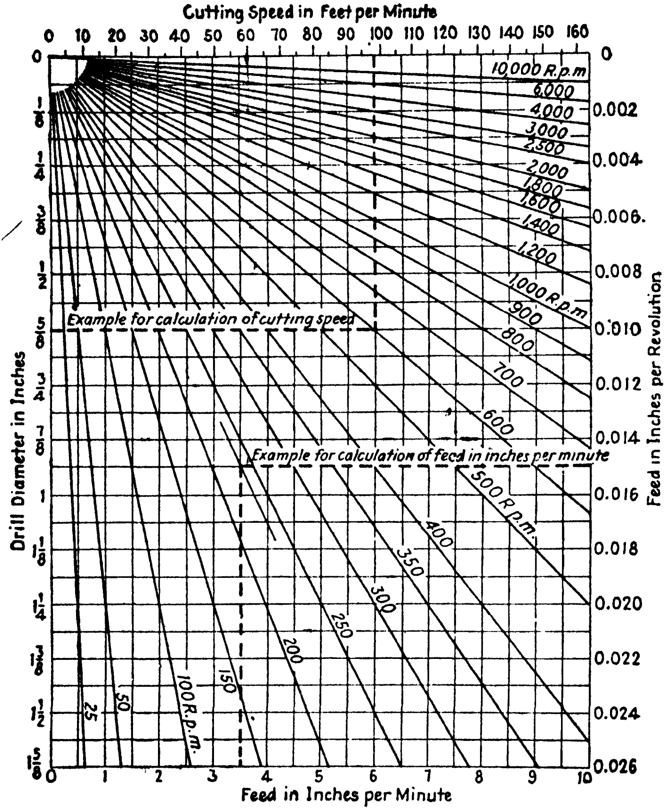


FIG. 19.—Speed and Feed Chart for Drills

CHART FOR ESTIMATING SPEEDS AND FEEDS OF DRILLED WORK

This chart, Fig. 19, is designed to work from the spindle speed of the drilling machine in even hundreds of revolutions per minute. This shows that a ⅝-inch drill running at 600 revolutions per minute gives nearly 100 feet per minute cutting speed. With a feed of 0.015 inch per revolution, this would drill 9 inches per minute, as is found by following the line of feed per revolution until it meets the line of 600 revolutions per minute, then going down to the base line. The dotted line shows that to get a feed of 3½ inches per minute at the rate of 0.015 inch per revolution, the drill must run about 235 revolutions per minute. All such estimates can easily be made by using this chart.

BRITISH STANDARD TOLERANCES ON POINT DIAMETERS OF TWIST DRILLS

	INCHES
Up to and including ¼ inch diameter	+0.000 to 0.0005
Over ¼ inch and up to and including 1 inch diameter	+0.000 to 0.0010
Over 1 inch and up to and including 2 inches diameter	+0.000 to 0.0015
Over 2 inches diameter	+0.000 to 0.0020

Drills for Reamed Holes.—The user should specify drills to give desired reaming allowance. Normally $\frac{1}{64}$ inch is sufficient for reaming and is supplied by some makers when the size is not specified.

Taper-Pin Drills.—The Sheffield Twist Drill & Steel Co., Ltd., England, make a special high-speed drill for drilling taper-pin holes from the solid metal. The drills are tapered ¼ inch per foot and have serrated cutting lips. They are made with both straight and taper shanks for all sizes of taper pins.

Hardness of Drills.—Drill makers contend that a drill should never be judged by its hardness when tested with a file. Mere hardness is not a gage of its cutting ability. Some drills that may seem soft to a fine file give excellent results in actual drilling.

DRILLING ON MULTIPLE-SPINDLE MACHINES

Makers of multiple-drilling machines advise conservative speeds and feeds because the failure of a single drill stops production on the machine. The National Automatic Tool Company suggests starting at 70 feet per minute on cast iron and increasing gradually if it seems advisable. In many cases 80 and 90 feet can be used, and 120 feet has been found possible in a few cases. For steel of the 1020 class, they start at 60 feet, with 70 and 80 feet a possibility under favorable conditions. With alloy steels both hardness and toughness affect the speed, and it is sometimes necessary to reduce the cutting speed to 50 feet. This refers to high-speed drills.

Reaming can usually be done at from one-half to two-thirds of the drilling speed. Tapping varies from as low as 15 feet in steels to as high as 48 feet in cast iron. The size of the tap drill or the amount of thread desired affects this materially.

Soluble oils and soda compounds are used for drilling, reaming, and tapping. Some prefer brushing the taps with lard or mineral oil between operations as this removes the chips. With multiple tapping, however, this takes time, and a flood of lubricant is generally used.

Cast iron is drilled dry. In tapping, an oil is usually brushed on the taps. Aluminum and brass are drilled and tapped dry or with kerosene or soluble oil as a lubricant. When in doubt use a lubricant.

TABLE 8.—DRILLING DATA FOR MULTIPLE-SPINDLE DRILL HEADS—KRUEGER

	Drilling Aluminum Feed, 8 Inches per Minute					Drilling Cast Iron Feed, 5 Inches per Minute					Drilling Semi-Steel Feed, 4 Inches per Minute				
Diam. of Drill, in Inches	Cutting Speed, Feet per Minute	Spindle Speed, Rev. per Minute	Feed per Rev., in Inches	Feeding Press., in Pounds	Horse-Power Required	Cutting Speed, Feet per Minute	Spindle Speed, Rev. per Minute	Feed per Rev., in Inches	Feeding Press., in Pounds	Horse-Power Required	Cutting Speed, Feet per Minute	Spindle Speed, Rev. per Minute	Feed per Rev., in Inches	Feeding Press., in Pounds	Horse-Power Required
1/4	131	2000	0.0040	47	0.07	54.6	834	0.006	230	0.10	46.0	702	0.0057	250	0.10
5/16	145	1760	0.0045	58	0.10	58.5	715	0.007	290	0.15	49.5	606	0.0066	335	0.15
3/8	157	1600	0.0050	68	0.15	61.5	625	0.008	360	0.22	52.0	533	0.0075	420	0.22
7/16	167	1450	0.0055	81	0.20	63.5	555	0.009	440	0.30	54.5	476	0.0084	515	0.30
1/2	175	1330	0.0060	95	0.26	65.5	500	0.010	520	0.39	56.3	430	0.0093	615	0.39
9/16	181	1230	0.0065	108	0.33	66.8	454	0.011	610	0.50	57.6	392	0.0102	725	0.50
5/8	187	1140	0.0070	124	0.40	68.0	416	0.012	720	0.62	58.8	360	0.0110	845	0.62
11/16	192	1065	0.0075	140	0.50	69.3	385	0.013	820	0.75	59.9	333	0.0120	970	0.75
3/4	197	1000	0.0080	157	0.59	70.0	357	0.014	930	0.89	60.8	310	0.0129	1095	0.89
13/16	201	940	0.0085	175	0.69	70.7	333	0.015	1050	1.04	61.7	290	0.0138	1230	1.04
7/8	204	890	0.0090	195	0.80	71.5	312	0.016	1175	1.20	62.3	272	0.0147	1365	1.20
15/16	207	842	0.0095	215	0.92	72.2	294	0.017	1310	1.38	62.9	256	0.0156	1520	1.38
1	210	800	0.0100	235	1.04	72.8	278	0.018	1460	1.57	63.6	242	0.0165	1680	1.57
1 1/8	214	727	0.0110	280	1.22	73.8	250	0.020	1760	2.00	64.3	218	0.0180	1995	2.00
1 1/4	218	666	0.0120	330	1.65	74.6	228	0.022	2120	2.45	65.2	199	0.0200	2350	2.45
1 3/8	222	615	0.0130	380	1.96	75.0	208	0.024	2470	3.00	66.00	183	0.0220	2750	3.00

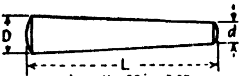
TABLE 8.—DRILLING DATA FOR MULTIPLE-SPINDLE DRILL HEADS—KRUEGER.—*Continued*

	Drilling Machine Steel (S.A.E. No. 1020) Feed, 3 Inches per Minute					Drilling 0.70 Per Cent Carbon Steel Feed, 2 Inches per Minute					Drilling Nickel-Chromium Steel Feed, 1.5 Inches per Minute				
1/4	36.4	555	0.0054	260	0.12	31.9	488	0.0041	276	0.12	26.0	395	0.0038	285	0.12
5/16	39.6	484	0.0062	350	0.20	34.0	417	0.0048	365	0.20	27.0	340	0.0044	380	0.20
3/8	42.1	428	0.0070	450	0.28	35.7	364	0.0055	465	0.28	29.5	300	0.0050	485	0.28
7/16	44.2	385	0.0078	570	0.37	37.0	322	0.0062	580	0.37	30.7	268	0.0056	600	0.37
1/2	45.7	349	0.0086	700	0.47	38.0	290	0.0069	695	0.47	31.7	242	0.0062	725	0.47
9/16	47.0	319	0.0094	840	0.60	38.8	263	0.0076	830	0.60	32.5	220	0.0068	860	0.60
5/8	48.2	294	0.0102	990	0.74	39.5	241	0.0083	975	0.74	33.2	203	0.0074	1000	0.74
11/16	49.1	272	0.0110	1160	0.90	40.0	221	0.0090	1130	0.90	33.8	188	0.0080	1150	0.90
3/4	50.0	254	0.0118	1340	1.06	40.5	206	0.0097	1290	1.06	34.2	174	0.0086	1310	1.06
13/16	50.7	238	0.0126	1530	1.24	40.9	193	0.0104	1460	1.24	34.7	163	0.0092	1480	1.24
7/8	51.3	224	0.0134	1740	1.45	41.3	180	0.0111	1650	1.45	35.1	153	0.0098	1665	1.45
15/16	51.9	211	0.0142	1950	1.67	41.7	169	0.0118	1840	1.67	35.4	144	0.0104	1850	1.67
1	52.4	200	0.0150	2200	1.90	42.0	160	0.0125	2050	1.90	35.7	136	0.0110	2050	1.90
1 1/8	53.3	181	0.0166	2680	2.40	42.4	144	0.0139	2500	2.40	36.3	123	0.0122	2500	2.40
1 1/4	54.4	165	0.0182	3180	2.97	42.7	131	0.0150	3000	2.90	36.6	112	0.0134	3000	2.90
1 3/8	54.6	151	0.0198	3800	3.50	43.0	120	0.0160	3550	3.50	37.0	103	0.0146	3550	3.50

TABLE 9.—TABLE OF DRILL SIZES FOR TAPER PINS

Drill Sizes for Taper Pins

The table gives the drill sizes for taper pins ranging in lengths by ¼ inch from No. 0, ¾ inch long, to No. 10, 6 inches long. The diameter of the small end of the pin for each length is given in the fourth column with the drill size in the fifth column. Radius of rounded ends varies from ½ to 2 diameters of pin, usually measured at the large end.



$$d = D - \frac{\text{Length of Pin} \times 0.25}{12}$$

No. Pin	L	D	d	No. of Drill
0	¾″	0.156″	0.1404″	28
0	1″	0.156″	0.1352″	29
1	¾″	0.172″	0.1564″	22
1	1″	0.172″	0.1512″	24
1	1¼″	0.172″	0.146″	26
2	¾″	0.193″	0.1774″	16
2	1″	0.193″	0.1722″	17
2	1¼″	0.193″	0.167″	18
2	1½″	0.193″	0.1618′	20
3	¾″	0.219″	0.2034″	6
3	1″	0.219″	0.1982″	8
3	1¼″	0.219″	0.193″	10
3	1½″	0.219″	0.1878″	12
3	1¾″	0.219″	0.1825″	14
4	¾″	0.250″	0.2344″	15/64″
4	1″	0.250″	0.2292″	15/64″
4	1¼″	0.250″	0.224″	1
4	1½″	0.250″	0.2187″	2
4	1¾″	0.250′	0.2135″	3
4	2″	0.250″	0.2083″	4
5	¾″	0.289″	0.2734″	17/64″
5	1″	0.289″	0.2682″	17/64″
5	1¼″	0.289″	0.263″	17/64″
5	1½″	0.289″	0.2577″	¼″
5	1¾″	0.289″	0.2525″	¼″
5	2″	0.289″	0.2473″	¼″
5	2¼″	0.289″	0.2421″	15/64″
6	¾″	0.341″	0.3254″	21/64″
6	1″	0.341″	0.3201″	21/64″
6	1¼″	0.341″	0.315″	5/16″
6	1½″	0.341″	0.310″	5/16″
6	1¾″	0.341″	0.3045″	19/64″
6	2″	0.341″	0.2994″	19/64″
6	2¼″	0.341″	0.2941″	19/64″
6	2½″	0.341″	0.2889″	9/32″
6	2¾″	0.341″	0.2837″	9/32″
6	3″	0.341″	0.2785″	9/32″
6	3¼″	0.341″	0.2733″	17/64″
7	1″	0.409″	0.3881″	25/64″
7	1¼″	0.409″	0.3829″	25/64″
7	1½″	0.409″	0.3777″	⅜″
7	1¾″	0.409′	0.3725″	⅜″
7	2″	0.409″	0.3673″	⅜″
7	2¼″	0.409″	0.3621″	23/64″
7	2½″	0.409″	0.3569″	23/64″
7	2¾″	0.409″	0.3517″	23/64″
7	3″	0.409″	0.3465″	11/32″
7	3¼″	0.409″	0.3413″	11/32″
7	3½″	0.409″	0.3361″	11/32″
7	3¾″	0.409″	0.3309″	21/64′
8	1¼″	0.492″	0.466″	15/32″
8	1½″	0.492″	0.4608″	15/32″
8	1¾″	0.492″	0.4555″	29/64″
8	2″	0.492″	0.4503″	29/64″
8	2¼″	0.492″	0.4451″	29/64″
8	2½″	0.492″	0.4399″	7/16″
8	2¾″	0.492″	0.4347″	7/16″
8	3″	0.492″	0.4295″	7/16″
8	3¼″	0.492″	0.4243″	27/64″
8	3½″	0.492″	0.4191″	27/64″
8	3¾″	0.492″	0.4139″	27/64″
8	4″	0.492″	0.4087″	13/32″
8	4¼″	0.492″	0.4035″	13/32″
8	4½″	0.492″	0.3982″	13/32″
9	1½″	0.591″	0.5597″	9/16″
9	1¾″	0.591″	0.5545″	35/64″
9	2″	0.591″	0.5493″	35/64″
9	2¼″	0.591″	0.5441″	35/64″
9	2½″	0.591″	0.5389″	35/64″
9	2¾″	0.591″	0.5337″	17/32″
9	3″	0.591″	0.5285″	17/32″
9	3¼″	0.591″	0.5233″	17/32″
9	3½″	0.591″	0.5181″	33/64″
9	3¾″	0.591″	0.5129″	33/64
9	4″	0.591″	0.5077″	33/64″
9	4¼″	0.591″	0.5025″	½″
9	4½′	0.591″	0.4972″	½″
9	4¾″	0.591″	0.4929″	½″
9	5″	0.591″	0.4868″	31/64″
9	5¼″	0.591″	0.4816″	31/64″
9	5½″	0.591″	0.4764″	31/64″
10	1½″	0.706″	0.6747″	43/64″
10	1¾″	0.706″	0.6695″	43/64″
10	2″	0.706″	0.6643″	43/64″
10	2¼″	0.706″	0.6591″	21/32″
10	2½″	0.706″	0.6539″	21/32″
10	2¾″	0.706″	0.6487″	21/32″
10	3″	0.706″	0.6435″	41/64″
10	3¼″	0.706″	0.6383″	41/64″
10	3½″	0.706″	0.6331′	41/64′
10	3¾″	0.706″	0.6278″	⅝″
10	4″	0.706″	0.6226″	⅝″
10	4¼″	0.706″	0.6174″	⅝″
10	4½″	0.706″	0.6122″	39/64″
10	4¾″	0.706″	0.6078″	39/64″
10	5″	0.706″	0.6018″	39/64″
10	5¼″	0.706″	0.5966″	19/32″
10	5½″	0.706″	0.5914″	19/32″
10	5¾″	0.706″	0.5862″	19/32″
10	6″	0.706″	0.581″	37/64″

Taper is ¼ inch per foot—sizes from 5–0 to 00; 00000 = 0.094; 0000 = 0.109; 000 = 0.125; 00 = 0.141 at large end.

SUGGESTED SPEEDS FOR TUNGSTEN-CARBIDE DRILLS

Because of their construction, tungsten-carbide-tipped twist drills are not usually recommended for hard materials. They are, however, well adapted for drilling highly abrasive materials and materials of low strength, such as concrete, bakelite, hard rubber, slate, stone, glass, carbon, copper, graphite alloy, and similar materials.

Recent information from the Cincinnati-Bickford Tool Company lists the following cutting speeds which have been successfully used for the materials listed:

Materials	Suggested Speed Feet per Minute
Slate	40
Marble	60 to 80
Sandstone	30
Glass	20 to 30
Pure carbon	100
Copper graphite alloy	60 to 70

Very light feeds are recommended for these materials.

Lubricants for Drilling

Hard tool and alloy steel	Soluble oil, turpentine, soluble oil or lard oil.
Mild steel or machinery steel	Soluble oil or a good cutting compound.
Brass or phosphor bronze	Dry or with soluble oil or lard oil.
Aluminum	Soluble oil or lard oil.
Cast iron	Work dry. If possible keep the drill cooled with a jet of compressed air.

On soft steels, sulphurized oil saves up to 30 per cent in power over dry drilling, and on tool steel, the saving is about 20 per cent. On Bessemer screw stock, oil saves comparatively little power. For aluminum and its alloys, a little lard oil mixed with mineral oil gives good results.

A CUTTING COMPOUND FOR DRILLING HARD SPOTS IN STEEL

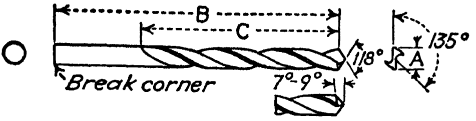
An old-time compound for use in drilling hard steel has proved successful in electric welds in 5 per cent nickel steel, after turpentine and other compounds had failed. The compound is

1 part powdered sulphur
1 part cylinder oil
2 parts castor oil

SIMPLIFIED OR PREFERRED DRILL SIZES

Users of twist drills have long felt that there was an unnecessary number of drill sizes below ½ inch, owing to the overlapping of frac-

TABLE 10.—PREFERRED SIZES OF STRAIGHT-SHANK DRILLS



Size	Regular Series		Long Series	
A	Drill Length B	Flute Length C	Drill Length B	Flute Length C
0.0156	1	1/4		
0.0180	1	1/4		
0.0200	1	1/4		
0.0225	1	1/4		
0.0240	1	1/4		
0.0260	1 1/4	7/16		
0.0280	1 1/4	7/16		
0.0295	1 1/4	7/16		
0.0312	1 1/4	7/16		
0.0330	1 1/4	7/16		
0.0350	1 1/4	7/16		
0.0370	1 1/2	5/8		
0.0390	1 1/2	5/8		
0.0410	1 1/2	5/8		
0.0430	1 1/2	5/8		
0.0453	1 1/2	5/8		
0.0469	1 1/2	5/8		
0.0492	1 1/2	5/8		
0.0512	1 3/4	13/16		
0.0531	1 3/4	13/16		
0.0550	1 3/4	13/16		
0.0571	1 3/4	13/16		
0.0591	1 3/4	13/16		
0.0610	1 3/4	13/16		
0.0625	1 3/4	13/16		
0.0650	2	1		
0.0670	2	1		
0.0700	2	1		
0.0730	2	1		
0.0760	2	1		
0.0781	2	1		
0.0810	2 1/4	1 3/16		
0.0827	2 1/4	1 3/16		
0.0860	2 1/4	1 3/16		
0.0890	2 1/4	1 3/16		
0.0906	2 1/4	1 3/16		
0.0937	2 1/4	1 3/16		
0.0960	2 1/2	1 3/8		
0.0995	2 1/2	1 3/8		
0.1024	2 1/2	1 3/8		
0.1040	2 1/2	1 3/8		
0.1063	2 1/2	1 3/8		
0.1094	2 1/2	1 3/8		
0.1130	2 3/4	1 9/16		
0.1160	2 3/4	1 9/16		
0.1200	2 3/4	1 9/16		
0.1220	2 3/4	1 9/16		
0.1250	2 3/4	1 9/16	4 3/4	2 1/2
0.1285	3	1 3/4	5	2 11/16
0.1299	3	1 3/4	5	2 11/16
0.1339	3	1 3/4	5	2 11/16
0.1360	3	1 3/4	5	2 11/16
0.1378	3	1 3/4	5	2 11/16
0.1406	3	1 3/4	5	2 11/16
0.1440	3 1/4	1 15/16	5 1/4	3 1/8
0.1470	3 1/4	1 15/16	5 1/4	3 1/8
0.1520	3 1/4	1 15/16	5 1/4	3 1/8
0.1562	3 1/4	1 15/16	5 1/4	3 1/8
0.1610	3 1/2	2 1/8	5 1/2	3 7/16
0.1660	3 1/2	2 1/8	5 1/2	3 7/16
0.1693	3 1/2	2 1/8	5 1/2	3 7/16
0.1719	3 1/2	2 1/8	5 1/2	3 7/16
0.1730	3 1/2	2 1/8	5 1/2	3 7/16
0.1770	3 1/2	2 1/8	5 1/2	3 7/16
0.1800	3 3/4	2 5/16	5 3/4	3 11/16
0.1850	3 3/4	2 5/16	5 3/4	3 11/16
0.1875	3 3/4	2 5/16	5 3/4	3 11/16
0.1910	3 3/4	2 5/16	5 3/4	3 11/16
0.1935	3 3/4	2 5/16	5 3/4	3 11/16
0.1960	3 3/4	2 5/16	5 3/4	3 11/16
0.1990	4	2 9/16	6	3 15/16
0.2031	4	2 9/16	6	3 15/16
0.2090	4	2 9/16	6	3 15/16
0.2130	4	2 9/16	6	3 15/16
0.2187	4	2 9/16	6	3 15/16
0.2244	4 1/4	2 13/16	6 1/4	4 1/8
0.2283	4 1/4	2 13/16	6 1/4	4 1/8
0.2344	4 1/4	2 13/16	6 1/4	4 1/8
0.2402	4 1/4	2 13/16	6 1/4	4 1/8
0.2460	4 1/4	2 13/16	6 1/4	4 1/8
0.2500	4 1/2	3 1/8	6 1/2	4 5/16
0.2520	4 1/2	3 1/8	6 1/2	4 5/16
0.2570	4 1/2	3 1/8	6 1/2	4 5/16
0.2610	4 1/2	3 1/8	6 1/2	4 5/16
0.2656	4 1/2	3 1/8	6 1/2	4 5/16
0.2720	4 1/2	3 1/8	6 1/2	4 5/16
0.2770	4 1/2	3 1/8	6 1/2	4 5/16
0.2812	4 3/4	3 3/8	6 3/4	4 1/2
0.2854	4 3/4	3 3/8	6 3/4	4 1/2
0.2913	4 3/4	3 3/8	6 3/4	4 1/2
0.2969	4 3/4	3 3/8	6 3/4	4 1/2
0.3020	4 3/4	3 3/8	6 3/4	4 1/2
0.3071	4 3/4	3 3/8	6 3/4	4 1/2
0.3125	5	3 5/8	7	4 11/16
0.3160	5	3 5/8	7	4 11/16
0.3230	5	3 5/8	7	4 11/16
0.3281	5	3 5/8	7	4 11/16
0.3320	5	3 5/8	7	4 11/16
0.3390	5	3 5/8	7	4 11/16
0.3437	5 1/4	3 7/8	7 1/4	4 15/16
0.3480	5 1/4	3 7/8	7 1/4	4 15/16
0.3543	5 1/4	3 7/8	7 1/4	4 15/16
0.3594	5 1/4	3 7/8	7 1/4	4 15/16
0.3680	5 1/4	3 7/8	7 1/4	4 15/16
0.3750	5 5/8	4 1/8	7 5/8	5 1/8
0.3860	5 5/8	4 1/8	7 5/8	5 1/8
0.3906	5 5/8	4 1/8	7 5/8	5 1/8
0.3970	5 5/8	4 1/8	7 5/8	5 1/8
0.4062	5 5/8	4 1/8	7 5/8	5 1/8
0.4219	5 5/8	4 1/8	7 5/8	5 1/8
0.4375	6 1/8	4 7/16	8 1/8	5 7/16
0.4531	6 1/8	4 7/16	8 1/8	5 7/16
0.4687	6 1/8	4 7/16	8 1/8	5 7/16
0.4844	6 1/8	4 7/16	8 1/8	5 7/16
0.5000	6 1/8	4 7/16	8 1/8	5 7/16

tional, letter, wire gage, and millimeter sizes from 0.0156 to 0.500 inch. After long study and several modifications, the sizes in Table 10 are recommended by A.S.M.E. Technical Committee No. 7

TAP DRILLS

Except in special cases, tap drills should always be larger than. the root diameter of the tap. In average practice, the drill gives about three-quarters thread depth. Some metals flow enough to make nearly a full thread, especially with a dull tap.

The simple rule of subtracting the pitch of one thread from the tap diameter, is accurate enough for most work. Following this:

A $\frac{3}{8}$-inch tap, 16-thread, would be $\frac{3}{8}$ minus $\frac{1}{16} = \frac{5}{16}$ drill; a $\frac{3}{4}$-inch tap, 10-thread, would be $\frac{3}{4}$ minus $\frac{1}{10} = \frac{75}{100} - \frac{10}{100}$ or $0.75 - 0.10 = \frac{65}{100}$ or 0.65, or a little over $\frac{5}{8}$ inch; so a $\frac{5}{8}$-inch drill will do nicely. With a 1-inch tap we have $1 - \frac{1}{8} = \frac{7}{8}$-inch drill, which is a little large but leaves enough thread for most cases.

Taps should be between 0.002 and 0.003 inch large in outside diameter, for clearance between top and bottom of thread.

DRILLING HARDENED STEEL

New drill known as "Hardsteel" are now available for drilling holes in armor plate and hardened steels of any kind, even the high speed steels. They are made from a cast alloy by the Black Drill Company, Cleveland, Ohio, and are three-cornered in shape, with small hollows ground in each cutting face for chip clearance. They should not be used in soft materials, but only in materials that cannot be drilled by the usual drill.

It takes 5 seconds or more after the drill contacts the work before it begins to cut. By that time it has built up enough frictional heat to anneal the metal in actual contact with the drill point. Then the drill begins to cut and regular chips form. Sufficient pressure should be kept on the drill to maintain the flow of chips. Hand feed is preferred to maintain a "feel" of the way the drill cuts.

These drills are run at high speed, the following table giving approximate speeds for the sizes shown. Should the drill fail to cut properly, try a higher speed. In drilling work hardening materials it may be advisable to increase the chip clearance groove to take out a wider chip. Clear the chips from the hole every $\frac{1}{8}$ inch of depth drilled. Short drills are to be preferred where they can be used. The drills can be ground by hand and the shape of the new drill should be maintained in grinding. They are used dry.

DRILLING SPEEDS WITHOUT COOLANT

Size of Drill, in Inches	Speed, in R.P.M.	Size of Drill, in Inches	Speed, in R.P.M.
$\frac{1}{8}$	2500–3000	$\frac{7}{16}-\frac{1}{2}$	950
$\frac{1}{8}-\frac{3}{16}$	2000	$\frac{1}{2}-\frac{5}{8}$	900
$\frac{3}{16}-\frac{1}{4}$	1600	$\frac{5}{8}-\frac{3}{4}$	750–800
$\frac{1}{4}-\frac{5}{16}$	1500	$\frac{3}{4}-\frac{7}{8}$	700
$\frac{5}{16}-\frac{3}{8}$	1200	$\frac{7}{8}-1$	600
$\frac{3}{8}-\frac{7}{16}$	1000		

TABLE 11.—BASIC THREAD DIMENSIONS AND TAP DRILL SIZES

AMERICAN MACHINE SCREW

Nominal Size	Outside Diameter in Inches	Pitch Diameter in Inches	Root Diameter in Inches	Commercial Tap Drill to Produce Approx. 75% Full Thread	Decimal Equivalent of Tap Drill
0-80-F	0.0600	0.0519	0.0438	3/64	0.0469
1-56	0.0730	0.0614	0.0498	54	0.0550
64-C	0.0730	0.0629	0.0527	53	0.0595
72-F	0.0730	0.0640	0.0550	53	0.0595
2-56-C	0.0860	0.0744	0.0628	50	0.0700
64-F	0.0860	0.0759	0.0657	50	0.0700
3-48-C	0.0990	0.0855	0.0719	47	0.0785
56-F	0.0990	0.0874	0.0758	45	0.0820
4-32	0.1120	0.0917	0.0714	45	0.0820
36	0.1120	0.0940	0.0759	44	0.0860
40-C	0.1120	0.0958	0.0795	43	0.0890
48-F	0.1120	0.0985	0.0849	42	0.0935
5-36	0.1250	0.1078	0.0889	40	0.0980
40-C	0.1250	0.1088	0.0925	38	0.1015
44-F	0.1250	0.1102	0.0955	37	0.1040
6-32-C	0.1380	0.1177	0.0974	36	0.1065
36	0.1380	0.1200	0.1019	34	0.1110
40-F	0.1380	0.1218	0.1055	33	0.1130
7-30	0.1510	0.1294	0.1077	31	0.1200
32	0.1510	0.1307	0.1104	31	0.1200
36	0.1510	0.1330	0.1149	1/8	0.1250
8-30	0.1640	0.1423	0.1207	30	0.1285
32-C	0.1640	0.1437	0.1234	29	0.1360
36-F	0.1640	0.1460	0.1279	29	0.1360
40	0.1640	0.1478	0.1315	28	0.1405
9-24	0.1770	0.1499	0.1229	29	0.1360
30	0.1770	0.1553	0.1337	27	0.1440
32	0.1770	0.1567	0.1364	26	0.1470
10-24-C	0.1900	0.1629	0.1359	25	0.1495
28	0.1900	0.1668	0.1436	23	0.1540
30	0.1900	0.1684	0.1467	22	0.1570
32-F	0.1900	0.1697	0.1494	21	0.1590
12-24-C	0.2160	0.1889	0.1619	16	0.1770
28-F	0.2160	0.1928	0.1696	14	0.1820
32	0.2160	0.1957	0.1754	13	0.1850

C = coarse-thread standard. F = fine-thread standard.

TABLE 12.—BASIC THREAD DIMENSIONS AND TAP DRILL SIZES

AMERICAN THREAD

Nominal Size	Outside Diameter in Inches	Pitch Diameter in Inches	Root Diameter in Inches	Commercial Tap Drill to Produce Approx. 75% Full Thread	Decimal Equivalent of Tap Drill
1/16-64	0.0625	0.0524	0.0422	3/64	0.0469
72	0.0625	0.0535	0.0445	3/64	0.0469
5/64-60	0.0781	0.0673	0.0563	1/16	0.0625
72	0.0781	0.0691	0.0601	52	0.0635
3/32-48	0.0938	0.0803	0.0667	49	0.0730
50	0.0938	0.0808	0.0678	49	0.0730
7/64-48	0.1094	0.0959	0.0823	43	0.0890
1/8-32	0.1250	0.1047	0.0844	3/32	0.0937
40	0.1250	0.1088	0.0925	38	0.1015

TABLE 12.—BASIC THREAD DIMENSIONS AND TAP DRILL SIZES.—*Continued*

AMERICAN THREADS

Nominal Size	Outside Diameter in Inches	Pitch Diameter in Inches	Root Diameter in Inches	Commercial Tap Drill to Produce Approx. 75% Full Thread	Decimal Equivalent to Tap Drill
9/64-40	0.1406	0.1244	0.1081	32	0.1160
5/32-32	0.1563	0.1360	0.1157	1/8	0.1250
36	0.1563	0.1382	0.1202	30	0.1285
11/64-32	0.1719	0.1505	0.1313	9/64	0.1406
3/16-24	0.1875	0.1604	0.1334	26	0.1470
32	0.1875	0.1672	0.1469	22	0.1570
13/64-24	0.2031	0.1760	0.1490	20	0.1610
7/32-24	0.2188	0.1919	0.1646	16	0.1770
32	0.2188	0.1985	0.1782	12	0.1890
15/64-24	0.2344	0.2073	0.1806	10	0.1935
1/4-20	0.2500	0.2175	0.1850	7	0.2010
24	0.2500	0.2229	0.1959	4	0.2090
27	0.2500	0.2260	0.2019	3	0.2130
28	0.2500	0.2268	0.2036	3	0.2130
32	0.2500	0.2297	0.2094	7/32	0.2187
5/16-18	0.3125	0.2764	0.2403	F	0.2570
20	0.3125	0.2800	0.2476	17/64	0.2656
24	0.3125	0.2854	0.2584	I	0.2720
27	0.3125	0.2884	0.2644	J	0.2770
32	0.3125	0.2922	0.2719	9/32	0.2812
3/8-16	0.3750	0.3344	0.2938	5/16	0.3125
20	0.3750	0.3425	0.3100	21/64	0.3281
24	0.3750	0.3479	0.3209	Q	0.3320
27	0.3750	0.3509	0.3269	R	0.3390
7/16-14	0.4375	0.3911	0.3447	U	0.3680
20	0.4375	0.4050	0.3726	25/64	0.3906
24	0.4375	0.4104	0.3834	X	0.3970
27	0.4375	0.4134	0.3894	Y	0.4040
1/2-12	0.5000	0.4459	0.3918	27/64	0.4219
13	0.5000	0.4501	0.4001	27/64	0.4219
20	0.5000	0.4675	0.4351	29/64	0.4531
24	0.5000	0.4729	0.4459	29/64	0.4531
27	0.5000	0.4759	0.4519	15/32	0.4687
9/16-12	0.5625	0.5084	0.4542	31/64	0.4844
18	0.5625	0.5264	0.4903	33/64	0.5156
27	0.5625	0.5384	0.5144	17/32	0.5312
5/8-11	0.6250	0.5660	0.5069	17/32	0.5312
12	0.6250	0.5709	0.5168	35/64	0.5469
18	0.6250	0.5889	0.5528	37/64	0.5781
27	0.6250	0.6009	0.5769	19/32	0.5937
11/16-11	0.6875	0.6285	0.5694	19/32	0.5937
16	0.6875	0.6469	0.6063	5/8	0.6250
3/4-10	0.7500	0.6850	0.6201	21/32	0.6562
12	0.7500	0.6959	0.6418	43/64	0.6719
16	0.7500	0.7094	0.6688	11/16	0.6875
27	0.7500	0.7259	0.7019	23/32	0.7187
13/16-10	0.8125	0.7476	0.6826	23/32	0.7187
7/8- 9	0.8750	0.8029	0.7307	49/64	0.7656
12	0.8750	0.8209	0.7668	51/64	0.7969
14	0.8750	0.8286	0.7822	13/16	0.8125
18	0.8750	0.8389	0.8028	53/64	0.8281
27	0.8750	0.8509	0.8269	27/32	0.8437

TABLE 12.—BASIC THREAD DIMENSIONS AND TAP DRILL SIZES—*Continued*

AMERICAN THREADS

Nominal Size	Outside Diameter in Inches	Pitch Diameter in Inches	Root Diameter in Inches	Commercial Tap Drill to Produce Approx. 75% Full Thread	Decimal Equivalent of Tap Drill
15/16 - 9	0.9375	0.8654	0.7932	53/64	0.8281
1 - 8	1.0000	0.9188	0.8376	7/8	0.8750
12	1.0000	0.9459	0.8918	59/64	0.9219
14	1.0000	0.9536	0.9072	15/16	0.9375
27	1.0000	0.9759	0.9519	31/32	0.9687
1 1/8 - 7	1.1250	1.0322	0.9394	63/64	0.9844
12	1.1250	1.0709	1.0168	1 3/64	1.0469
1 1/4 - 7	1.2500	1.1572	1.0644	1 7/64	1.1094
12	1.2500	1.1959	1.1418	1 11/64	1.1719
1 3/8 - 6	1.3750	1.2668	1.1585	1 7/32	1.2187
12	1.3750	1.3209	1.2668	1 19/64	1.2969
1 1/2 - 6	1.5000	1.3917	1.2835	1 11/32	1.3437
12	1.5000	1.4459	1.3918	1 27/64	1.4219
1 5/8 -5 1/2	1.6250	1.5070	1.3888	1 29/64	1.4531
1 3/4 - 5	1.7500	1.6201	1.4902	1 9/16	1.5625
1 7/8 - 5	1.8750	1.7451	1.6152	1 11/16	1.6875
2 - 4 1/2	2.0000	1.8557	1.7113	1 25/32	1.7812
2 1/8 - 4 1/2	2.1250	1.9807	1.8363	1 29/32	1.9062
2 1/4 - 4 1/2	2.2500	2.1057	1.9613	2 1/32	2.0312
2 3/8 - 4	2.3750	2.2126	2.0502	2 1/8	2.1250
2 1/2 - 4	2.5000	2.3376	2.1752	2 1/4	2.2500
2 3/4 - 4	2.7500	2.5876	2.4252	2 1/2	2.5000
3 - 3 1/2	3.0000	2.8145	2.6288	2 23/32	2.7187
3 1/4 - 3 1/2	3.2500	3.0645	2.8788	2 31/32	2.9687
3 1/2 - 3 1/4	3.5000	3.3002	3.1003	3 3/16	3.1875
3 3/4 -3	3.7500	3.5335	3.3170	3 7/16	3.4375
4 3	4.0000	3.7835	3.5670	3 11/16	3.6875

TABLE 13.—TAP DRILLS FOR UNIFORM PITCH THREAD SERIES*

8 Pitch = 0.1250 inch		12 Pitch = 0.0833 inch				16 Pitch = 0.0625 inch	
Nominal Size Inches	Drill Size Inches	Nominal Size Inches	Drill Size Inches	Nominal Size Inches	Drill Size Inches	Nominal Size Inches	Drill Size Inches
1	7/8	1/2	0.417	3 1/4	3.167	3/4	11/16
1 1/8	1	9/16	0.479	3 1/2	3.417	7/8	13/16
1 1/4	1 1/8	5/8	0.542	3 3/4	3.667	1	15/16
1 3/8	1 1/4	11/16	0.604	4	3.917	1 1/8	1 1/16
1 1/2	1 3/8	3/4	0.667	4 1/4	4.167	1 1/4	1 3/16
1 5/8	1 1/2	13/16	0.729	4 1/2	4.417	1 3/8	1 5/16
1 3/4	1 5/8	7/8	0.792	4 3/4	4.667	1 1/2	1 7/16
1 7/8	1 3/4	15/16	0.854	5	4.917	1 5/8	1 9/16
2	1 7/8	1	0.917	5 1/4	5.167	1 3/4	1 11/16
2 1/8	2	1 1/16	0.979	5 1/2	5.417	1 7/8	1 13/16
2 1/4	2 1/8	1 1/8	1.042	5 3/4	5.667	2	1 15/16
2 1/2	2 3/8	1 3/16	1.104	6	5.917	2 1/8	2 1/16
2 3/4	2 5/8	1 1/4	1.167			2 1/4	2 3/16
3	2 7/8	1 5/16	1.229			2 1/2	2 7/16
3 1/4	3 1/8	1 3/8	1.292			2 3/4	2 11/16
3 1/2	3 3/8	1 7/16	1.354			3	2 15/16
3 3/4	3 5/8	1 1/2	1.417			3 1/4	3 3/16
4	3 7/8	1 5/8	1.542			3 1/2	3 7/16
4 1/4	4 1/8	1 3/4	1.667			3 3/4	3 11/16
4 1/2	4 3/8	1 7/8	1.792			4	3 15/16
4 3/4	4 5/8	2	1.917				
5	4 7/8	2 1/4	2.167				
5 1/4	5 1/8	2 1/2	2.417				
5 1/2	5 3/8	2 3/4	2.667				
5 3/4	5 5/8	3	2.917				
6	5 7/8						

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* H. W. Bearce, Bureau of Standards.

TABLE 14.—BRITISH TAP DRILLS

British Standard Pipe Thread		British Association Thread		
Nominal Bore of Pipe—Inches	Diameter of Tap Drill—Inches	Designating Number	Diameter of Tap Drill	
			Steel	C.I. or Brass
1/8	11/32		No.	No.
1/4	15/32	0	8–9	10
3/8	19/32	1	15–16	16–17
1/2	3/4	2	23	24–25
5/8	53/64	3	28	29
3/4	31/32	4	31	32
7/8	1 7/64	5	36–37	37–38
1	1 7/32	6	41–42	42–43
1 1/4	1 35/64	7	45	46
1 1/2	1 25/32	8	48	49–50
1 3/4	2 1/32	9	51	52–53
2	2 1/4	10	53	54–55
2 1/4	2 1/2	11	54–55	56
2 1/2	2 7/8	12	61	62
2 3/4	3 9/64	13	63	64
3	3 25/64	14	69	70
3 1/4	3 19/32	15	71	71
3 1/2	3 27/32	16	74	74
3 3/4	4 3/32			
4	4 11/32			

TABLE 15.—DRILLS AND REAMERS FOR DOWEL PINS

SIZES OF ROD		DRILLS AND REAMERS FOR DRIVE FITS			DRILLS FOR CLEARANCE	
No. of Gage (Stubbs Steel Wire)	Dia.	Size of Drill	Dia. of Drill	Dia. of Reamer	Size of Drill	Dia. of Drill
54	.055	No. 55	.052		No. 54	.055
45	.081	" 47	.0785		" 46	.081
33	.112	" 36	.1065	.110	" 33	.113
30	.127	" 31	.120	.125	" 30	.1285
21	.157	" 24	.152	.155	" 22	.157
10	.191	" 13	.185	.189	" 11	.191
	.252	C	.242	.250 –.2505	F	.257
	.315	5/16 Reamer Drill	.307	.3125–.313	O	.316
V	.377	3/8 "	.366	.375 –.3755	V	.377
	.439	7/16 "	.427	.4375–.438		
	.503	1/2 "	.489	.500 –.5005		
	.628	5/8 "	.616	.625 –.6255		
	.753	3/4 "	.734 (47/64)	.750 –.7505		

BODY OR CLEARANCE DRILLS

Clearance between bolt body or threads and the work varies with the nature of the work: 1/64 inch is considered *fine*, 1/32 inch *moderate*, and 1/16 inch *coarse* or *heavy*. Drills should be specified to the clearance desired by adding it to the nominal size. A 5/8 inch clearance drill should be ordered 41/64, 21/32, or 11/16 inch, depending on the grade of work.

DRILL END LENGTHS

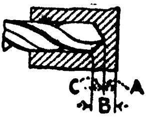
It is often necessary in designing to allow for drilling to a certain depth so as to give the thickness of metal *A* necessary at the bottom of the hole to withstand pressure.

The table gives the dimension *C* for usual sizes of drills. This is deducted from *B* to give the actual thickness of metal at *A*. This table is for standard drill points of 118 degrees included angle.

TABLE 16.—DRILL END LENGTHS

Dia.	*C*	*C* in nearest 1/64	Gage No.	Dia.	*C*	*C* in Nearest 1/64	Gage No.	Dia.	*C*	*C* in Nearest 1/64
2	0.60086	39/64	1	0.2280	0.06850	5/64	41	0.0960	0.02884	1/32
1 15/16	0.58208	37/64	2	0.2210	0.06640	5/64	42	0.0935	0.02809	1/32
1 7/8	0.56331	9/16	3	0.2130	0.06400	1/16	43	0.0890	0.02674	1/32
1 13/16	0.54453	35/64	4	0.2090	0.06279	1/16	44	0.0860	0.02584	1/32
1 3/4	0.52576	33/64	5	0.2055	0.06174	1/16	45	0.0820	0.02464	1/32
1 11/16	0.50698	1/2	6	0.2040	0.06129	1/16	46	0.0810	0.02433	1/32
1 5/8	0.48820	31/64	7	0.2010	0.06039	1/16	47	0.0785	0.02858	1/32
1 9/16	0.46942	15/32	8	0.1990	0.05979	1/16	48	0.0760	0.02283	1/32
1 1/2	0.45065	29/64	9	0.1960	0.05888	1/16	49	0.0730	0.02193	1/32
1 7/16	0.43187	7/16	10	0.1935	0.05813	1/16	50	0.0700	0.02103	1/32
1 3/8	0.41309	13/32	11	0.1910	0.05738	1/16	51	0.0670	0.02013	1/32
1 5/16	0.39431	25/64	12	0.1890	0.05678	1/16	52	0.0635	0.01908	1/64
1 1/4	0.37554	3/8	13	0.1850	0.05558	1/16	53	0.0595	0.01788	1/64
1 3/16	0.35676	23/64	14	0.1820	0.05468	1/16	54	0.0550	0.01652	1/64
1 1/8	0.33798	11/32	15	0.1800	0.05408	1/16	55	0.0520	0.01562	1/64
1 1/16	0.31931	5/16	16	0.1770	0.05318	1/16	56	0.0465	0.01397	1/64
1	0.30046	19/64	17	0.1730	0.05197	1/16	57	0.0430	0.01292	1/64
31/32	0.29104	19/64	18	0.1695	0.05092	3/64	58	0.0420	0.01262	1/64
15/16	0.28165	9/32	19	0.1660	0.04987	3/64	59	0.0410	0.01232	1/64
29/32	0.27226	17/64	20	0.1610	0.04837	3/64	60	0.0400	0.01202	1/64
7/8	0.26288	17/64	21	0.1590	0.04777	3/64	61	0.0390	0.01172	1/64
27/32	0.25349	1/4	22	0.1570	0.04717	3/64	62	0.0380	0.01142	1/64
13/16	0.24410	1/4	23	0.1540	0.04627	3/64	63	0.0370	0.01112	1/64
25/32	0.23471	15/64	24	0.1520	0.04567	3/64	64	0.0360	0.01082	1/64
3/4	0.22532	7/32	25	0.1495	0.04491	3/64	65	0.0350	0.01052	1/64
23/32	0.21593	7/32	26	0.1470	0.04416	3/64	66	0.0330	0.00991	1/64
11/16	0.20655	13/64	27	0.1440	0.04326	3/64	67	0.0320	0.00961	1/64
21/32	0.19716	13/64	28	0.1405	0.04221	3/64	68	0.0310	0.00931	1/64
5/8	0.18777	3/16	29	0.1360	0.04086	3/64	69	0.0293	0.00879	1/64
19/32	0.17838	11/64	30	0.1285	0.03861	3/64	70	0.0280	0.00841	1/64
9/16	0.16900	11/64	31	0.1200	0.03605	3/64	71	0.0260	0.00781	1/64
17/32	0.15960	5/32	32	0.1160	0.03485	1/32	72	0.0250	0.00751	1/64
1/2	0.15022	5/32	33	0.1130	0.03395	1/32	73	0.0240	0.00721	1/64
15/32	0.14083	9/64	34	0.1110	0.03335	1/32	74	0.0225	0.00676	1/64
7/16	0.13144	1/8	35	0.1100	0.03305	1/32	75	0.0210	0.00631	1/64
13/32	0.12205	1/8	36	0.1065	0.03200	1/32	76	0.0200	0.00601	1/64
3/8	0.11266	7/64	37	0.1040	0.03124	1/32	77	0.0180	0.00541	1/64
11/32	0.10327	7/64	38	0.1015	0.03049	1/32	78	0.0160	0.00481	..
5/16	0.09388	3/32	39	0.0995	0.02989	1/32	79	0.0145	0.00436	..
9/32	0.08450	3/32	40	0.0980	0.02944	1/32	80	0.0135	0.00406	..
1/4	0.07511	5/64								
7/32	0.06572	1/16								
3/16	0.05633	1/16								
5/32	0.04942	3/64								
1/8	0.03755	1/32								
3/32	0.02817	1/32								
1/16	0.01878	1/64								
1/32	0.00939	1/64								

Formula, $C = \frac{0.60086\ Diam.}{2}$



SECTION IV

REAMERS AND REAMING

Reamers are commonly used tools for enlarging holes to the required diameter and finish. The amount of enlargement is usually slight and does not always meet modern requirements as to roundness and finish. Reamers are formed by having flutes along the body which form cutting edges and provide channels for escape of chips. Much standardization has been done by reamer makers and Technical Committee No. 20 of the A.S.M.E. was appointed to prepare a standard. Most of the recommendations follow the practice of reamer makers.

Reamers usually have a back taper of about 0.0001 to 0.0025 inch per inch of length, decreasing the diameter toward the shank, for clearance.

Tolerances of reamer diameters are always plus, from basic size up to 0.0004 in. for reamers to 1/4 inch diameter; from basic size up to 0.0005 inch for reamers up to 1 inch; and up to 0.0006 inch for larger sizes.

BRITISH STANDARDS FOR REAMERS

Tolerances on British Standard reamers are always plus. The amount of oversize on nearly all reamers is as follows:

Size, in Inches	Amount of Oversize in Inches
1/8 to 1/4	0.0003 to 0.0006
5/16 to 9/16	0.0004 to 0.0008
5/8 to 15/16	0.0005 to 0.0010
1 to 1 7/16	0.0006 to 0.0012
1 1/2 to 2	0.0007 to 0.0014

The number of flutes is optional but runs about as follows:

Size in Inches	Number of Flutes
1/8 to 3/8	4 to 6
13/32 to 3/4	4 to 8
25/32 to 1 1/8	8 to 10
1 3/16 to 1 1/2	8 to 14

The kinds or types of reamers in common use are shown and described. They are usually made with either straight or helical flutes. A number are shown in Fig. 1.

TYPES OF REAMERS

Expansion Hand Reamers.—Made with either straight or helical flutes. Primarily designed to enlarge reamed holes by a few thousandths.

Hand Reamers.—Solid reamers, slightly tapered on the starting end. Used on high-grade work by clamping the square in a vise and passing the work over the reamer with a screw-like motion.

Jobber's Reamers.—Similar to hand reamers but designed for machine use.

Shell Reamers.—Made either for roughing or finishing and held on a tapered arbor with driving lugs. Holes tapered to fit the special arbor, which fit several reamer sizes.

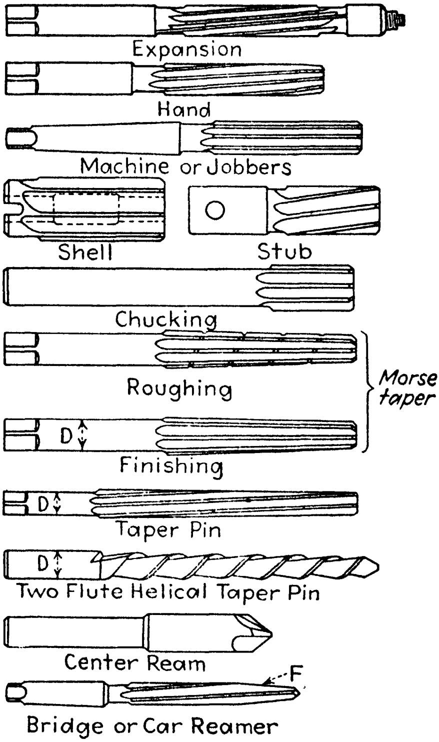


FIG. 1.—Common Types of Reamers

Expansion Chucking Reamers.—Adjustable for reaming holes to close tolerances. Made only with straight flutes but either straight or taper shanks.

Fluted Chucking Reamers.—Designed for machine use, and have a bevel point so that most of the cutting is done on the end. Straight or taper shanks.

Rose Chucking Reamers.—For use in turret lathes and screw machines. Ground cylindrically, without radial relief, and cut only on the end. Usually made with a back taper of 0.005″ in the flute length. Recommended only for free-working steel, and under the best conditions as to alignment and with a flood of lubricant. Straight or taper shanks.

Stub Screw Machine Reamers.—For use in automatic screw machines and for jobs requiring short tools. Specially adapted for floating holders. Regularly furnished with right-hand cut and left-hand helix.

Morse Taper Reamers.—For reaming the Morse taper hole in sockets and machine spindles. Made only with straight flutes in either squared or taper shanks. Roughing reamers notched to break up the chips.

Taper Pin Reamers.—For machine taper pins all have a taper of ¼ inch to the foot. The point of each reamer will enter the hole reamed by the next size smaller. Made with either straight, slow or fast helical flutes.

Taper Bridge Reamers.—For reaming rivet and bolt holes in structural work, boiler plate, etc. Tapered at point to facilitate entering holes out of alignment. Taper shanks only and are made in both straight and helical flutes.

Taper Car Reamers.—Similar to Bridge Reamers but shorter. Made with either straight or helical flutes.

Center Reamers.—For centering lathe work or countersinking for screw heads. Have eccentric relief and made in either 60, 72, or 82 deg. included angle of point.

Machine Countersinks.—Similar to Center reamer.

ARBORS FOR SHELL REAMERS

General dimensions for arbors for shell reamers are given in the tables for both straight and taper shanks. The corners of the driving slots in the reamer should be rounded to avoid cracks in hardening. Dimensions of arbors and of the driving slots and driving lugs in the arbors are given in Table 2.

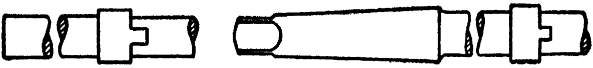


TABLE 1.—STRAIGHT- AND TAPER-SHANK ARBORS FOR SHELL REAMERS

No. of Arbor	Diameter of Reamer, in Inches	Length Over All, in Inches	Diameter Shank, in Inches	Morse Taper
4	¾	9	½	No. 2
5	1 3/16 to 1	9½	⅝	No. 2
6	1 1/16 to 1¼	10	¾	No. 3
7	1 5/16 to 1⅝	11	⅞	No. 3
8	1 11/16 to 2	12	1⅛	No. 4
9	2 1/16 to 2½	13	1⅜	No. 4
10	2 9/16 to 3	14	1⅝	No. 5

Length Tolerances

1/16 inch on Nos. 4 to 5; 3/32 inch on Nos. 6 to 8; ⅛ inch on Nos. 9 to 10; straight-shank tolerance minus 0.0005 to 0.002 inch; hole in reamer, ⅛ inch per foot.

Allowance for Reaming.—For holes up to ¼ inch leave 0.005 to 0.008 inch; for ¾ inch about 0.015 inch; and up to 1/32 inch for 2 inch diameter. One large shop leaves 0.015 inch for all holes in steel and 0.030 inch for aluminum and magnesium.

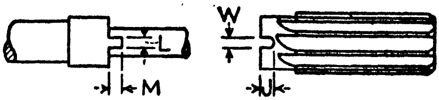


TABLE 2.—DRIVING SLOTS AND LUGS IN SHELL REAMERS AND SHELL-REAMER ARBORS

The hole in shell reamers shall have a taper of 0.125 inch per foot, with arbors tapered to correspond.

General Dimensions

Diameter of Hole in Reamer at Large End, in Inches*	No. of Arbor	Dimensions, in Inches					
		Range of Reamer Sizes		Driving Slot		Lug on Arbor	
		Above	To and Including	Width *W*	Depth *J*	Width *L*	Depth *M*
0.250	3	0'.4687 ($\frac{15}{32}$)	0.6250 ($\frac{5}{8}$)	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{7}{64}$	$\frac{1}{8}$
0.375	4	0.6250 ($\frac{5}{8}$)	0.7182 ($\frac{23}{32}$)	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{9}{64}$	$\frac{5}{32}$
0.500	5	0.7812 ($\frac{25}{32}$)	1.0312 ($1\frac{1}{32}$)	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{11}{64}$	$\frac{7}{32}$
0.625	6	1.0312 ($1\frac{1}{32}$)	1.2812 ($1\frac{9}{32}$)	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{11}{64}$	$\frac{7}{32}$
0.750	7	1.2812 ($1\frac{9}{32}$)	1.6562 ($1\frac{21}{32}$)	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{15}{64}$	$\frac{9}{32}$
1.000	8	1.6562 ($1\frac{21}{32}$)	2.0000 (2)	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{15}{64}$	$\frac{9}{32}$
1.250	9	2.0000 (2)	2.5000 ($2\frac{1}{2}$)	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{19}{64}$	$\frac{11}{32}$
1.500	10	2.5000 ($2\frac{1}{2}$)	3.0000 (3)	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{19}{64}$	$\frac{11}{32}$
1.750	11	3.0000 (3)	3.5000 ($3\frac{1}{2}$)	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{23}{64}$	$\frac{13}{32}$
2.000	12	3.5000 ($3\frac{1}{2}$)	4.0000 (4)	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{31}{64}$	$\frac{15}{32}$
2.250	13	4.0000 (4)	4.5000 ($4\frac{1}{2}$)	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{31}{64}$	$\frac{15}{32}$
2.500	14	4.500 ($4\frac{1}{2}$)	5.5000 ($5\frac{1}{2}$)	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{39}{64}$	$\frac{9}{16}$
2.750	15	5.5000 ($5\frac{1}{2}$)	6.5000 ($6\frac{1}{2}$)	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{39}{64}$	$\frac{9}{16}$

* Shell-reamer arbors are made slightly larger in diameter at the large end of the taper to permit a driving fit with the reamer.

NAMES OF REAMER PARTS

There are three main parts of a reamer: the shank; the body; and the point or entering portion (see Fig. 2). The terms used for shanks are:

Shank.—The part held in the hand wrench, vise, chuck or spindle for driving. May be cylindrical, tapered, squared or otherwise.

Taper Shank.—Generally a Morse Taper as is universally used for drills.

Straight Shank.—A cylinder smaller or larger than the reamers.

Square.—A square on the end of a straight shank to receive a wrench. Generally used on straight shank hand reamers.

Length of Square.—Length measured along the axis.

Size of Square.—Diameter across the flats of the square.

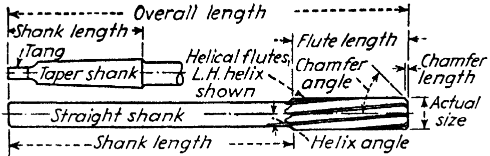
Square Shank.—Generally a tapered square for use in bit brace or ratchet.

Shank Length.—Measured along the axis from end of recess to extreme end of shank.

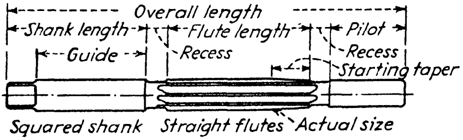
Taper-Shank Size.—Determined by the diameter, or by diameter at gage line and diameter at small end. Dimensions given in Tables, Section XVIII.

Tang.—Or tongue. Flatted portion on end of shank to fit a special holder to assist in driving the reamer. Used on either straight or taper shank. Not intended to carry the entire torque load of reaming as friction of the shank in the socket or holder should carry most of the torque.

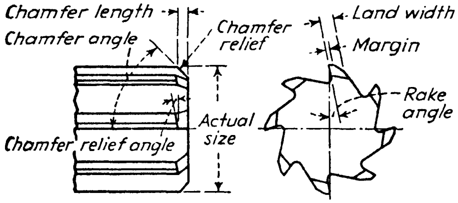
Tang Thickness.—Distance between flat surfaces.



CHUCKING REAMER, STRAIGHT AND TAPER SHANK



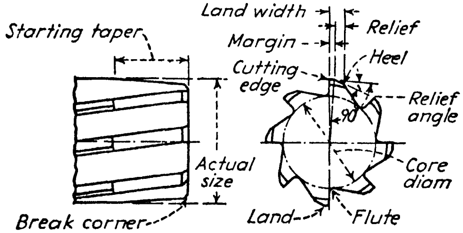
HAND REAMER, PILOT AND GUIDE



Straight flutes shown

Rake angle and right hand rotation shown

MACHINE REAMER POINT



Helical flutes, Left hand helix shown

Radial face (0° rake) and right hand rotation shown

HAND REAMER POINT

FIG. 2.—Names of Reamer Parts

THE REAMER BODY

Axis.—Center line about which reamer revolves.

Over-All Length.—Measured along the axis, of the entire tool from end to end.

Flute Length.—Measured along axis, from extreme front end of flutes to start of recess or neck. Where the reamer has no recess, flute length is from the end of the cutter runout.

Pilot.—A front non-cutting portion to aid in centering reamer.

Guide.—Noncutting portion of the tool, generally cylindrical, behind flutes, to assist in holding the reamer in alignment.

Recess or Neck.—Part between body and shank, usually of smaller diameter than either. Maker's name, size of tool, and kind of steel are commonly stamped in the recess.

Diameter.—Greatest diameter, measured diametrically across the land at the cutting edge.

Flute.—A groove, either helical or straight, extending through the point almost to the recess. It forms the front side of the cutting edge and provides room for cutting fluid and room for chip removal.

Tooth.—Volume of metal between two adjacent flutes. Generally taken to include all metal left between two adjacent flutes down to the web.

Web.—Metal below the bottoms of the flutes.

Web Thickness.—Distance between the bottoms of two opposite flutes measured along a diameter.

Cutting Edge or Lip.—Leading edge of a tooth. Formed by the intersection of the tooth face and the outside diameter.

Tooth Face.—The surface on which the chip impinges as it is removed from the work.

Depth of Flute.—Distance from the bottom of the flute to the top of the tooth.

Thickness at Base.—Length of the chord connecting the face of one tooth with its back as measured on a circle passing through the bottom of the root radius.

Root Radius.—Small radius at the bottom of flute connecting the back of one tooth with the face of the adjacent tooth.

Rake Angle.—Angle which the face of the tooth makes with a diameter through the cutting edge.

Land.—The periphery of that part of the reamer between the flutes.

Margin.—The cylindrical part of the land next to the cutting edge.

Land Clearance.—Sometimes called "radial clearance." That portion of the periphery of the tooth cut or, ground away to reduce friction in the hole. It enables the tooth to take a light scraping cut. Sometimes also called Backing-Off.

Land-Clearance Angle or Backing-Off Angle.—The slight angle between the land and the back of the tooth extending the length of the flute. See Fig. 2.

Back Taper or Longitudinal Relief.—Slight taper given from point to recess.

Flute Radius.—Radius of curve forming back of tooth.

Staggered Flutes or Unequally Spaced Flutes.—Where spaces between succeeding teeth are not equal. Used to prevent chatter and uneven cutting action.

Clearance Diameter.—The diameter measured diametrically on the relief angle.

Flute Run-Out.—Where bottom of flute rises to join the body periphery.

Expansion Slot.—Slot milled parallel to the cutting edges and used with an expansion screw to allow the reamer to be slightly expanded in diameter.

Helix Angle.—Angle which the flutes make with the axis.

Lead.—The distance along the axis of one complete turn of the helix. May be changed to helix angle by the equation: the tangent of the helix angle equals the circumference divided by the lead.

THE REAMER POINT

Entering Taper.—Slight taper on front end of reamer to start the cut gradually. Generally used on hand reamers.

Point.—Entire cone shaped portion at the cutting end of the reamer. The surfaces are cleared to form sharp cutting edges.

Point Clearance.—Clearance put on the point of the reamer, to allow it to cut its way into the hole.

Point-cutting edges of the teeth are sometimes called the primary cutting edges and do the principal cutting.

Body-cutting edges of the teeth form secondary cutting edges which finish the hole.

REAMER SPEEDS, FEEDS, AND LUBRICANTS

Several factors govern correct speeds and feeds. Material to be reamed and the reamer itself are most important. The finish desired, hand or machine operation, lubricant used, and whether reamer is piloted must all be considered.

In general, reamers can be run at about two-thirds drill speed for same size. It is best to start below this and increase to best productivity with satisfactory reamer life.

Feeds are from two to three times corresponding drill, but reamer wear and feed marks and desired production must be balanced against each other. For reamers smaller than ⅛ inch try 0.002 to 0.004 inch per revolution. For ⅛ to ¼ inch, try 0.004 to 0.008 inch; for ¼ to ½ inch, try 0.008 to 0.014 inch; for ½ to 1 inch, try 0.014 to 0.030 inch; above 1 inch, try 0.030 to 0.050 inch. Alloy and hard steels use the lighter feeds, and cast iron, brass, and aluminum use the heavier ones.

Tables 1 and 2 give suggested speeds and feeds for reamers in screw machines and in regular machine reaming.

Use of lubricant depends on the finish, production, material, and amount of stock removed. If stock removal is heavy, a flood of lubricant will carry away chips and heat. Good lard oil will often improve finish of hole reamed.

SHARPENING REAMERS

Reamers are correctly sharpened at the factory. To sharpen a dull reamer requires a good cutter grinder and a good mechanic.

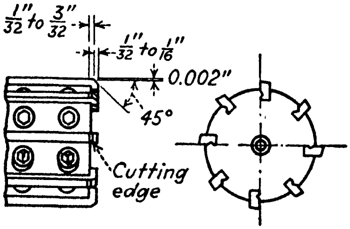


FIG. 3.—Cutting Edges of Reamer

Instruction books with the machine show in detail how they must be handled. The three kinds of clearances have been mentioned. Usually the point clearance is the only one for the user to watch, as this does most of the work and dulls frequently. Oil stones should only be used to remove burrs, not for sizing. Figures 3 to 11 give suggestions as to reamer action and sharpening.

Land clearance is most important, affecting both cutting action and reamer life. Double or single back-off with a small cylindrical land are most common. Lands vary from 0.005 to 0.015 inch. Clearance back of land is from 5 to 7 degrees. Double clearance is used on many inserted blade reamers, as in Fig. 7. Rose reamers have no land clearance, but only end cutting.

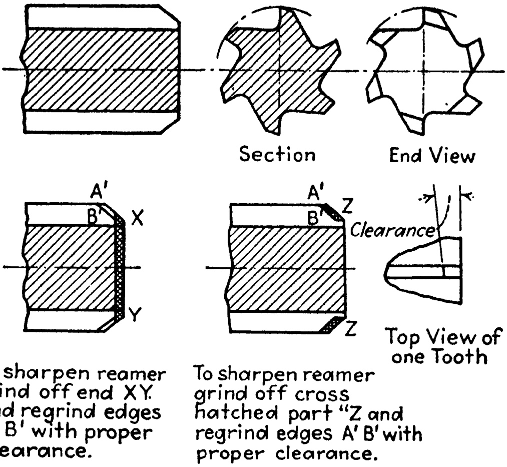

Section
End View
A'
B'
X
Y
A'
B'
Z
Z
Clearance
Top View of one Tooth
To sharpen reamer grind off end XY. and regrind edges A' B' with proper clearance.
To sharpen reamer grind off cross hatched part "Z and regrind edges A' B' with proper clearance.

FIG. 4.—Grinding Reamers

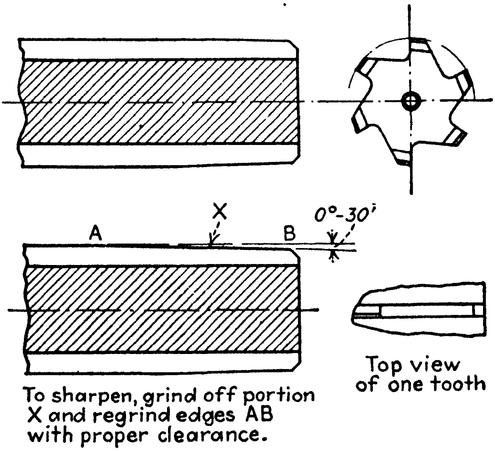

X
0°-30'
A
B
Top view of one tooth
To sharpen, grind off portion X and regrind edges AB with proper clearance.

FIG. 5.—Grinding Point for Entering Hole

Eccentric clearance is used on removable blade reamers. It is good for adjustable and hand reamers. Single or double back-off with no radial land is used for extremely free cutting, as in taper reamers.

Point clearance allows the reamer to cut its way into the hole. Machine reamers have from 80 to 100 degrees included angle.

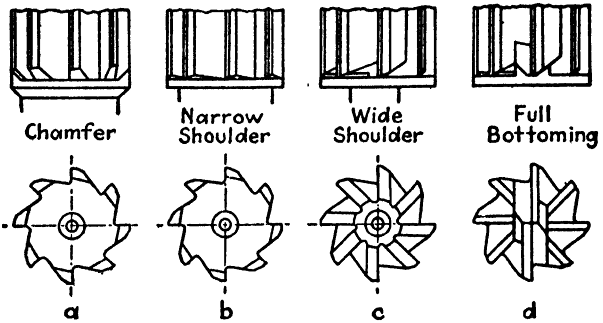


FIG. 6.—Reamer Ends for Different Work

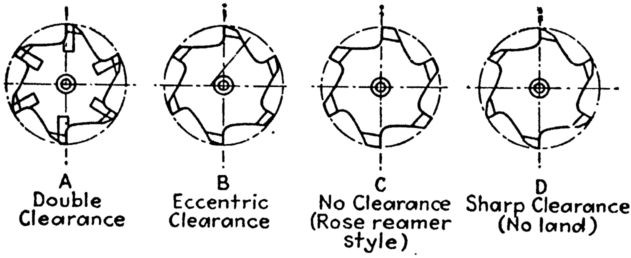


FIG. 7.—Clearance of Reamers

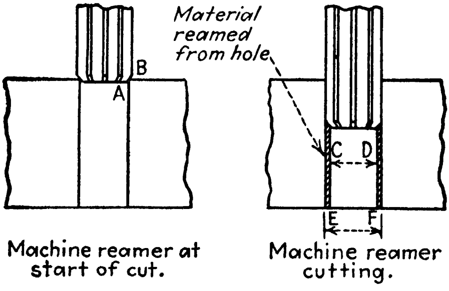


FIG. 8.—How a Machine Reamer Cuts

Hand reamers have an entering taper of about 1 degree total. The long taper point gives a scraping cut and makes a smooth, accurate hole. The point is beveled as with machine reamers.

The kind of material, stock to be removed, and method of reaming affect the type of point to be used. The illustrations in Figs. 8 and 9 are self-explanatory. They show an exaggerated amount of metal being removed to show cutting edges more clearly. Figures 10 and 11 show set-ups for grinding reamer.

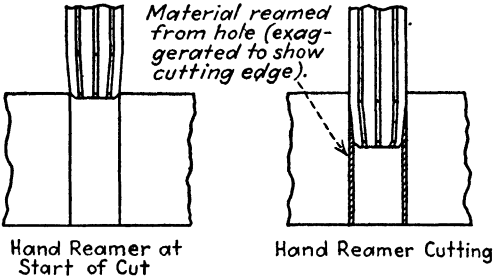

Material reamed from hole (exaggerated to show cutting edge).
Hand Reamer at Start of Cut
Hand Reamer Cutting

FIG. 9.—Hand-Reamer Action

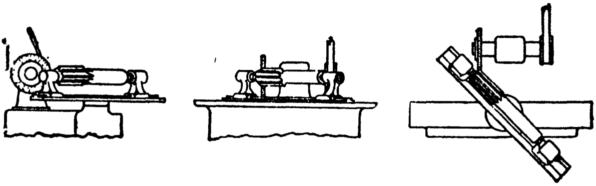


FIG. 10.—Reamer Grinding Set-Up

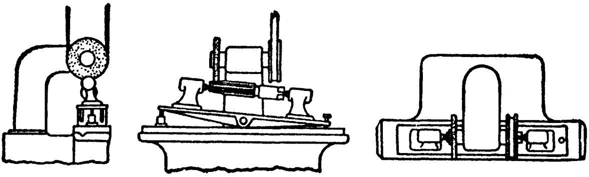


FIG. 11.—Set-Up for Point Grinding

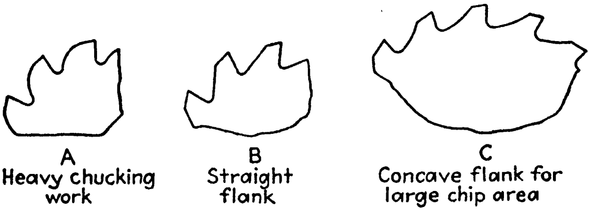


FIG. 12.—Three Forms of Flutes

FORM OF FLUTES

The form of reamer flute is important because it affects the strength of the tooth and the chip space. Both these are important in taper and machine reamers. Fillets are always necessary. Figure 12 shows three types, *A* for heavy chucking, *B* with straight flanks, and *C* with concave flank. This gives more chip space and is used for irregular spacing as lands can easily be kept at uniform width.

Chatter

Chattering is counteracted by using an odd number of flutes, helical flutes, or unequal spacing. The first method is usually ineffective and makes calipering difficult. Helical flutes are effective but cost more than unequal spacing. Heavy chucking reamers often have a right-hand helix to give rake to teeth on the end and aid in feeding reamer. For finishing, a left-hand helix is used in a right-hand cut to prevent drawing into the cut. A good example of unequal spacing is seen in Fig. 13.

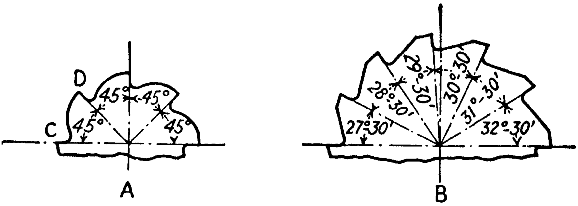


FIG. 13.—Unequal Spacing of Flutes

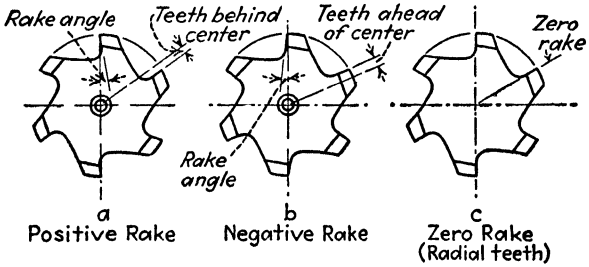
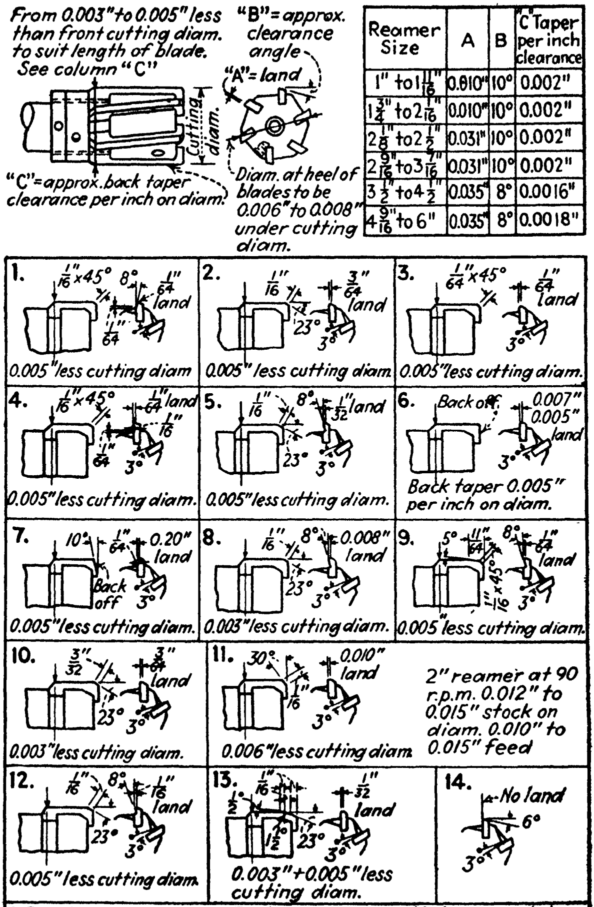


FIG. 14.—Rake of Reamer Teeth

Rake of Teeth

Examples of tooth rake are given in Fig. 14. In general, straight fluted reamers have a slight negative rake, whereas helical reamers have a slight positive rake. Suggested point grinding for different metals is shown in Fig. 15.


From 0.003" to 0.005" less than front cutting diam. to suit length of blade. See column "C"
"B" = approx. clearance angle
"A" = land
Cutting diam.
"C" = approx. back taper clearance per inch on diam.
Diam. at heel of blades to be 0.006" to 0.008" under cutting diam.
1. 1/16" × 45° 8° 1/64" land 1/64" 3°
0.005" less cutting diam
2. 1/16" 3/64" land 23° 3°
0.005" less cutting diam.
3. 1/64" × 45° 1/64" land 3°
0.005" less cutting diam.
4. 1/16" × 45° 1/64" land 1/16" 1/64" 3°
0.005" less cutting diam.
5. 1/16" 8° 1/32" land 23° 3°
0.005" less cutting diam.
6. Back off 0.007" 0.005" land 3°
Back taper 0.005" per inch on diam.
7. 10° 1/64" 0.20" land Back off 3°
0.005" less cutting diam.
8. 1/16" 8° 0.008" land 23° 3°
0.003" less cutting diam.
9. 5° 11/64" 8° 1/64" land 1/16" × 45° 3°
0.005" less cutting diam.
10. 3/32" 3/64" land 23° 3°
0.003" less cutting diam.
11. 30° 0.010" land 1/16" 3°
0.006" less cutting diam
2" reamer at 90 r.p.m. 0.012" to 0.015" stock on diam. 0.010" to 0.015" feed
12. 1/16" 8° 1/16" land 23° 3°
0.005" less cutting diam.
13. 1/16" 1/2" 1/32" land 1/2" 12° 23° 3°
0.003" to 0.005" less cutting diam.
14. No land 6° 3°

Reamer Size	A	B	"C" Taper per inch clearance
1" to 1 11/16"	0.010"	10°	0.002"
1 3/4" to 2 1/16"	0.010"	10°	0.002"
2 1/8" to 2 1/2"	0.031"	10°	0.002"
2 9/16" to 3 7/16"	0.031"	10°	0.002"
3 1/2" to 4 1/2"	0.035"	8°	0.0016"
4 9/16" to 6"	0.035"	8°	0.0018"

1. Red brass
2. Bronze, cast bronze
3. Cast iron, steel, hard aluminum casting
4. Copper, babbitt, soft bearing metal
5. Aluminum
6. Aluminum bronze
7. Lynite
8. Steel tubing
9. Steel forging
10. Malleable iron
11. Ampco metal
12. Die cast metal, zinc base
13. Nitralloy
14. Dow metal (cast magnesium alloy)

FIG. 15.—Reamers for Different Metals

The tables that follow give clearance used in grinding reamers for various purposes.

REAMER CLEARANCE

Ground with Cup Wheel 3" dia.—Tooth Rest to be Set Central with Grinding Wheel Spindle. Set Work holding Centers above Emery Wheel Center by Amount given below in Tables No. 1–2 and 3.

Set Tooth Rest Below Work Holding Centers. Amount given Below in Table No. 4

	TABLE 1 Hand Reamer for Steel Cut'g Clearance Land .006 Wide		TABLE 2 Hand Reamer for Cast Iron and Bronze Cut'g Clearance Land .025 Wide		TABLE 3 Chucking Reamer for Cast Iron and Bronze Cut'g Clearance Land .025 Wide		TABLE 4 Chucking Reamers for Steel Circular Ground	
Size of Reamer	For Cutting Clearance	For Second Clearance	For Cutting Clearance	For Second Clearance	For Cutting Clearance	For Second Clearance	Angle on End of Blade	For Cutting Clearance on Angle
1/2"	.012	.052	.032	.072	.040	.080	45 Degrees	.080
9/16"	.012	.057	.032	.072	.040	.080	45 "	.080
5/8"	.012	.062	.032	.072	.040	.090	45 "	.090
11/16"	.012	.067	.035	.095	.040	.100	45 "	.100
3/4"	.012	.072	.035	.095	.040	.100	45 "	.100
13/16"	.012	.077	.037	.095	.045	.125	45 "	.125
7/8"	.012	.082	.040	.120	.045	.125	45 "	.125
15/16"	.012	.087	.040	.120	.045	.125	45 "	.125
1"	.012	.092	.040	.120	.045	.125	45 "	.125
1 1/16"	.012	.097	.040	.120	.045	.125	45 "	.125
1 1/8"	.012	.102	.040	.120	.045	.125	45 "	.125
1 3/16"	.012	.106	.042	.122	.045	.125	45 "	.125
1 1/4"	.012	.112	.045	.145	.050	.160	45 "	.160
1 5/16"	.012	.118	.045	.145	.050	.160	45 "	.160
1 3/8"	.012	.122	.045	.145	.050	.160	45 "	.175
1 7/16"	.012	.127	.045	.145	.055	.175	45 "	.175
1 1/2"	.012	.132	.048	.168	.055	.175	45 "	.175
1 9/16"	.012	.137	.050	.170	.055	.175	45 "	.175
1 5/8"	.012	.142	.050	.170	.060	.200	45 "	.200
1 11/16"	.012	.147	.050	.170	.060	.200	45 "	.200
1 3/4"	.012	.152	.052	.192	.060	.200	45 "	.200
1 13/16"	.012	.157	.052	.192	.060	.200	45 "	.200
1 7/8"	.012	.162	.056	.196	.060	.200	45 "	.200
1 15/16"	.012	.167	.056	.196	.064	.200	45 "	.200
2"	.012	.172	.056	.216	.064	.224	45 "	.225
2 1/16"	.012	.172	.056	.216	.064	.224	45 "	.225
2 1/8"	.012	.172	.059	.219	.064	.224	45 "	.225
2 3/16"	.012	.172	.059	.219	.064	.224	45 "	.225
2 1/4"	.012	.172	.063	.223	.064	.224	45 "	.225
2 5/16"	.012	.172	.063	.223	.064	.224	45 "	.225
2 3/8"	.012	.172	.063	.223	.068	.228	45 "	.230
2 7/16"	.012	.172	.063	.223	.068	.228	45 "	.230
2 1/2"	.012	.172	.065	.225	.072	.232	45 "	.230
2 9/16"	.012	.172	.065	.225	.072	.232	45 "	.230
2 5/8"	.012	.172	.065	.225	.075	.235	45 "	.235
2 11/16"	.012	.172	.065	.225	.075	.235	45 "	.235
2 3/4"	.012	.172	.065	.225	.077	.237	45 "	.240

Mount Tooth Rest on Grinding Wheel Head

Mount Tooth Rest on Table of Machine

REAMER CLEARANCE

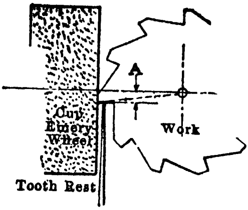
Ground with Cup Wheel 3" dia.—Tooth Rest to be Set Central with Grinding Wheel Spindle. Set Work holding Centers above Grinding Wheel Center by Amount given below in Tables No. 1–2 and 3.

Set Tooth Rest Below Work Holding Centers. Amount given Below in Table No. 4

	TABLE 1 Hand Reamer for Steel Cut'g Clearance Land .006 Wide		TABLE 2 Hand Reamer for Cast Iron and Bronze Cut'g Clearance Land .025 Wide		TABLE 3 Chucking Reamer for Cast Iron and Bronze Cut'g Clearance Land .025 Wide		TABLE 4 Chucking Reamers for Steel Circular Ground	
* Size of Reamer	For Cutting Clearance	For Second Clearance	For Cutting Clearance	For Second Clearance	For Cutting Clearance	For Second Clearance	Angle on End of Blade	For Cutting Clearance on Angle
2 13/16"	.012	.172	.065	.225	.077	.237	45 Degrees	.240
2 7/8"	.012	.172	.070	.230	.080	.240	45 "	.240
2 15/16"	.012	.172	.070	.230	.080	.240	45 "	.240
3"	.012	.172	.072	.232	.080	.240	45 "	.240
3 1/16"	.012	.172	.072	.232	.080	.240	45 "	.240
3 1/8"	.012	.172	.075	.235	.083	.240	45 "	.240
3 3/16"	.012	.172	.075	.235	.083	.243	45 "	.240
3 1/4"	.012	.172	.078	.238	.083	.243	45 "	.245
3 5/16"	.012	.172	.078	.238	.087	.243	45 "	.245
3 3/8"	.012	.172	.081	.241	.087	.247	45 "	.245
3 7/16"	.012	.172	.081	.241	.090	.247	45 "	.245
3 1/2"	.012	.172	.084	.244	.090	.250	45 "	.250
3 9/16"	.012	.172	.084	.244	.090	.250	45 "	.250
3 5/8"	.012	.172	.087	.247	.093	.253	45 "	.250
3 11/16"	.012	.172	.087	.247	.093	.253	45 "	.250
3 3/4"	.012	.172	.090	.250	.097	.257	45 "	.255
3 13/16"	.012	.172	.090	.250	.097	.257	45 "	.255
3 7/8"	.012	.172	.093	.253	.100	.260	45 "	.255
3 15/16"	.012	.172	.093	.253	.100	.260	45 "	.255
4"	.012	.172	.096	.256	.104	.264	45 "	.260
4 1/16"	.012	.172	.096	.256	.104	.264	45 "	.260
4 1/8"	.012	.172	.096	.256	.104	.264	45 "	.260
4 3/16"	.012	.172	.096	.256	.106	.266	45 "	.260
4 1/4"	.012	.172	.096	.256	.106	.266	45 "	.265
4 5/16"	.012	.172	.096	.256	.106	.266	45 "	.265
4 3/8"	.012	.172	.096	.256	.108	.268	45 "	.265
4 7/16"	.012	.172	.096	.256	.108	.268	45 "	.265
4 1/2"	.012	.172	.100	.260	.108	.268	45 "	.265
4 9/16"	.012	.172	.100	.260	.108	.268	45 "	.265
4 5/8"	.012	.172	.100	.260	.110	.270	45 "	.270
4 11/16"	.012	.172	.100	.260	.110	.270	45 "	.270
4 3/4"	.012	.172	.104	.264	.114	.274	45 "	.275
4 13/16"	.012	.172	.104	.264	.114	.274	45 "	.275
4 7/8"	.012	.172	.106	.266	.116	.276	45 "	.275
4 15/16"	.012	.172	.106	.266	.116	.276	45 "	.275
5"	.012	.172	.110	.270	.118	.278	45 "	.275
5 1/8"	.012	.172	.118	278				

Mount Tooth Rest on Grinding Wheel head

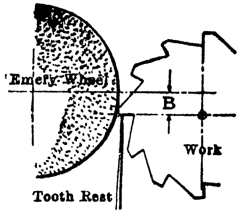
Mount Tooth Rest on Table of Machine



Cup Wheel Clearance Table

For setting tooth rest to obtain 5° or 7° clearance when grinding peripheral teeth of milling cutters with cup-shaped wheel. Tooth rest is set below work centers as at *A*, the distance being found in the table below.

Dia. Cutter Inches	For 5° Clearance A =	For 7° Clearance A =
¼	.011	.015
⅜	.015	.022
½	.022	.030
⅝	.028	.037
¾	.033	.045
⅞	.037	.052
1	.044	.060
1¼	.055	.075
1½	.066	.090
1¾	.077	.105
2	.088	.120
2¼	.099	.135
2½	.110	.150
2¾	.121	.165
3	.132	.180
3½	.154	.210
4	.176	.240
4½	.198	.270
5	.220	.300
5½	.242	.330
6	.264	.360



Disk Wheel Clearance Table

Giving distance *B* for setting work centers and tooth rest below center of wheel spindle to obtain 5° or 7° clearance with wheels of different diameters when grinding with periphery of disk wheel.

Dia. of Wheel Inches	For 5° Clearance B =	For 7° Clearance B =
2	.0937	.125
2¼	.099	.141
2½	.110	.156
2¾	.125	.172
3	.132	.187
3¼	.143	.203
3½	.154	.219
3¾	.165	.234
4	.176	.250
4¼	.187	.265
4½	.198	.281
4¾	.209	.297
5	.220	.312
5¼	.231	.328
5½	.242	.344
5¾	.253	.359
6	.264	.375
6¼	.275	.390
6½	.286	.406
6¾	.297	.421
7	.308	.437

Reaming Speeds and Feeds in Screw Machines

Diameter of Reamer, in Inches	Feed per Revolution, in Inches	Amount to Remove on Diameter, in Inches*	R.P.M. at Various Peripheral Speeds			
			Screw Stock at 40 Feet	Brass Rod at 130 Feet	Cast Iron at 45 Feet	Tool Steel at 25 Feet
1/8	0.005	0.0045	1222	3972	1375	764
3/16	0.006	0.0045	815	2648	917	509
1/4	0.007	0.006	611	1986	688	382
3/8	0.0085	0.006	407	1324	458	254
1/2	0.0105	0.008	306	993	344	191
5/8	0.012	0.008	245	795	275	153
3/4	0.014	0.008	204	662	229	127
1	0.016	0.010	153	497	172	95
1 1/4	0.018	0.010	122	397	138	76
1 1/2	0.020	0.010	102	331	115	63
1 3/4	0.022	0.010	87	284	98	54
2	0.024	0.013	76	248	86	48
2 1/4	0.026	0.013	68	220	76	42
2 1/2	0.028	0.013	61	199	69	38
2 3/4	0.030	0.013	56	181	63	35
3	0.032	0.013	51	165	57	32

* It is common practice to drill the hole to be reamed with a drill 1/64 inch undersize. This theoretically leaves 0.015 inch stock to remove on the diameter. However, the drill will cut oversize from 0.001 to 0.005 inch, depending on how accurately it is sharpened.

Reaming Speeds for Various Materials

Reamers with carbide blades can usually be run at a speed two to three times as great as that shown for high-speed reamers.

Material to Be Reamed	Cutter Speed in Ft. per Min.				
	High-Speed Steel	Super Hi-Speed Steel	Rexalloy	Tantalum Carbide	Tungsten Carbide
Aluminum	750		1150		1500
Brass, soft	125		200		475
Bronze, hard	100		130		325
Bronze, very hard	40	60			170
Cast iron soft	65	90	110		200
Cast iron hard	40	55	75		175
Cast iron chilled		40	50		150
Malleable iron	85	100	130		310
Steel soft	75	85		200	
Steel medium	65	75		165	
Steel hard	40	55		125	

SECTION V

TAPS AND TAPPING

Tapping of threaded holes plays such an important part in all machining that full information as to standard taps available, the terms used, and other data are essential. Few shops however make any but special taps so that detailed information as to these seems unnecessary. The kinds and sizes of taps that are available, together with the tolerances to which they are made, are given in the tables which follow. These are the standards of the American Standards Association, May, 1938. It must be remembered however that because of the wide variation in manufacturing methods and shop conditions, the size of the tapped hole cannot be guaranteed.

Cut thread taps made to the specifications given in the tables, when used under normal conditions, should, in the majority of cases, produce holes within Class 2 tolerances of the American Standard for screw threads.

Ground thread taps made to the specifications given in the tables when used under normal conditions, should, in the majority of cases, produce holes within Class 3 tolerances of the American Standard for screw threads.

Form of Thread.—The form of thread profile as specified for the taps covered by this standard is known as the "American Standard Form." The basic angle of thread between the sides of thread measured in an axial plane is 60 degrees. The line bisecting this 60-degree angle is perpendicular to the axis of the screw thread. The basic depth of the thread form h is found as follows:

$$h = 0.649519 \times p = \frac{0.649519}{n}.$$

The basic pitch diameter is the number obtained by subtracting the single thread depth from the basic major diameter; that is,

$$\text{Basic pitch diameter} = D - h$$

where D = major diameter.
h = depth of thread.
n = number of threads per inch.
p = pitch of thread.

DEFINITION OF TAPS

Standard Hand Tap.—Probably the original style of tap. So called because it is primarily for use by hand. Today, however, standard hand taps are used largely in machines. They are short taps with thread and shank of approximately the same length, the latter having a square to accommodate a tap wrench or other driving mechanism. Made in fractional sizes only.

Two- or Three-Fluted Tap.—Standard hand tap in every respect with two or three flutes. Suitable for machine use in tapping tough stringy metal.

Spiral (Helical) Pointed Hand Tap.—Standard hand tap with a fewer number of flutes and wider lands and with the cutting face of the first few threads ground at an angle to force the chips ahead to prevent clogging in the flutes.

Serial Hand Tap.—Standard hand taps in sets of three, the No. 1 being smaller than the No. 2 and the No. 2 being smaller than the No. 3, so that the work is divided among three taps. For very tough metal where a full thread cannot be cut at one pass. Distinguished by rings on the shank near the square.

Standard Machine Screw Tap.—This is similar to the standard hand tap except that it is made in numbered or machine screw sizes.

Spiral (Helical) Pointed Machine Screw Tap.—See Spiral (Helical) Pointed Hand Tap.

Stub Machine Screw Tap.—A machine screw tap with three flutes for all sizes and with a thread considerably shorter than a standard machine screw tap. For use in tapping thin metal, and to overcome breakage.

Spiral (Helical) Pointed Stub Machine Screw Tap.—Stub machine screw tap having two flutes with the cutting face of the first few threads ground at an angle to force the chips ahead and prevent clogging of the flutes.

Nut Tap.—A tap designed for the use of shops that tap their own nuts, generally from blanks supplied by a nut manufacturer. They are usually made with a taper in the angle of the thread so that a full form thread can be produced. The length overall, length of thread, and length of shank are longer than a standard hand tap.

Straight-Shank Tapper Tap.—A tap used by nut manufacturers in tapping nuts in vertical spindle machines. They are 12 or 15 inches long and the nuts are allowed to accumulate on the shank during the tapping operation. Shanks are machined to fit the various spindles in ordinary use. Made in both fractional and machine screw sizes.

Bent-Shank Tapper Tap.—A tap designed for use in an automatic tapping machine. The nuts are fed to the tap by a hopper, and there is a continual production of tapped product without stopping or reversing. Made in both fractional and machine screw sizes.

Pulley Tap.—Originally designed for use in tapping setscrew holes in the hubs of steel pulleys. The thread length is approximately equal to that of a standard hand tap, while the shank is full diameter of the thread and comes in various lengths. Recently the field for this tap has been expanded to meet the demands of those who want hand taps in longer lengths.

Taps for Beaman and Smith Holder.—A hand tap having a shank turned and splined to fit the friction tap holder put out by Beaman and Smith. The demand for this tap is gradually diminishing.

Straight Boiler Tap.—A hand tap having 12 threads per inch. Used by railroads and locomotive builders for tapping straight holes in boiler plate by hand.

Taper Boiler Tap.—A hand tap having a ¾-inch taper per foot, 12 threads per inch. Used by locomotive builders and railroad shops for tapping taper threaded holes in boiler sheets.

Mud or Washout Tap.—A hand tap having 1½-inch taper per foot, 12 threads per inch. Used in tapping and retapping the holes in mud drums in boiler work.

Staybolt Tap.—A tap having 12 threads per inch, provided with a long shank and reamer section. Used by boiler makers in tapping boiler sheets preparatory to inserting the staybolts. The tap is generally used in an air drill. Is also made with a V thread.

Spindle Staybolt Tap.—A short tap with a hole drilled through its entire length through which fits a spindle which acts as a guide. Used for tapping holes from the inside of fire boxes in locomotive work.

Taper Pipe Tap.—A hand tap used for tapping all kinds of American Standard taper pipe fittings, either by machine or by hand.

Straight Pipe Tap.—A hand tap the same as the taper pipe tap except that the threaded portion is straight and of proper size for tapping American Standard straight pipe thread.

Coupling Tap.—A tap used by the manufacturers of pipe couplings for tapping their product. It is a straight tap and passes entirely through the coupling during the threading operation. The shank is long enough to accommodate two tapped couplings.

Combined Pipe Tap and Drill.—A taper pipe tap having an extended point suitable for drilling and a taper square shank. Used for drilling and tapping holes in range boilers and similar work in one operation.

SCREW THREAD TERMS AND DEFINITIONS

Allowance.—The intentional difference in dimensions between the minimum hole and the maximum screw which indicates the minimum clearance or maximum interference intended between mating parts.

Angle of Thread.—The angle included between the sides of the thread, measured in an axial plane.

Axis of Screw.—The longitudinal central line through the screw from which all corresponding parts are equally distant.

Back Taper.—A slight relief on the body of the tap axially, which makes the pitch diameter of the thread near the shank somewhat smaller than that at the point.

Base of Thread.—The bottom section of a thread; the greatest section between the two adjacent roots.

Basic.—The theoretical standard size from which all variations are made.

Chamfer.—The tapering of the end of the tap by cutting away the crest of the first few threads to distribute the cutting action over several teeth. It also acts as a guide in starting the tap into a hole.

Crest.—The top surface joining the two sides of a thread.

Crest Clearance.—Defined on a screw form as the space between the crest of a thread and the root of its component.

Depth of Engagement.—The depth of a thread in contact, of two mating parts—measured radially.

Depth of Thread.—The depth of thread, in profile, is the distance between the top and the base of thread measured normal to the axis.

Flute.—That portion cut away between the lands.

Helix Angle—Thread.—The angle made by the helix of a thread at the pitch diameter with a plane perpendicular to the axis.

Helix Angle—Flute.—The flutes of taps are sometimes cut helically instead of straight to either pull the chips out of the hole or to bridge a gap such as a keyway. This helix angle is the angle made by the flute with the axis of the tap.

Interrupted Thread.—Applied to taps with an odd number of flutes so that every other tooth along the helix is removed. This reduces friction and allows thicker chips per tooth to be taken and is sometimes used for relatively large taps in tough metals.

Land.—That portion of a thread not cut away by the flutes.

Lead.—The distance a screw thread advances axially in one turn. On a single screw thread the lead and pitch are identical. On a double thread screw the lead is twice the pitch: on a triple thread screw the lead is three times the pitch, etc.

Length of Measurement.—The length of contact between two mating parts measured axially.

Limits.—The extreme dimensions which are prescribed to provide variations in fit and workmanship.

Major Diameter.—Commonly known as outside diameter. On a straight screw thread the major diameter is the largest diameter of the thread on the screw or nut. The term "major diameter" replaces the term "outside diameter" as applied to the thread of a screw and also the term "full diameter" as applied to the thread of a nut.

Minor Diameter.—Commonly known as core or root diameter. On a straight screw thread the minor diameter is the smallest diameter of the thread on the screw or nut. The term "minor diameter" replaces the term "core diameter" and "root diameter" as applied to the thread of a screw and also the term "inside diameter" as applied to the thread of a nut.

Number of Threads.—The number of threads in one inch of length.

Pitch.—The distance from a point on a screw thread to a corresponding point on the next thread measured parallel to the axis. The pitch equals one divided by the number of threads per inch.

Pitch Diameter.—On a straight screw thread the pitch diameter is the diameter of an imaginary cylinder which would pass through the threads at such points as to make the width of the thread and the width of the spaces between the threads at these points equal.

Rake.—Hook or undercut on the face of the teeth. When the faces are radial, the rake angle is zero. The rake angle is positive when the outer end of the teeth is ahead of the bottom. The rake angle is varied for different materials and conditions of tapping.

Relief.—The condition whereby metal is removed from behind the cutting edge to produce clearance and reduce friction. Taps should have the chamfer relieved and may or may not have relief in the angle and on the major diameter of the threads.

Root.—The bottom surface joining the sides of two adjacent threads.

Screw Thread.—A ridge of uniform section of some desired profile generated in the form of a helix on the inside or outside of a cylinder or cone.

Side of Thread.—The surface of the thread which connects the crest with the root.

Thread, V.—A form of thread having 60-degree angle and sharp top and bottom. Impossible in practice and always more or less modified to suit individual conditions.

Tolerance.—The difference between the limits or maximum and minimum dimensions of a given part. A tolerance may be expressed as plus or minus, or both. A total tolerance is the sum of a plus and minus tolerance.

MARKING

General.—All taps, dies, and other threading tools shall be clearly marked with the nominal size, number of threads per inch, together with the proper symbol to identify the thread form.

NC —indicating American Standard coarse-thread series.
NF —indicating American Standard fine-thread series.
N —indicating American Standard 8-pitch, 12-pitch, and 16-pitch series.
NS —indicating special threads with the American National form.
NH —indicating American National hose-coupling threads.
NPT —indicating American Standard taper-pipe threads.
NPS —indicating American Standard straight-pipe threads.
Grease—indicating a standardized undersize straight pipe thread for grease cup fittings.
V —indicating a 60-degree V thread usually with both the crest and root flatted several thousandths from the theoretical to users' specifications.
Acme —indicating American Standard 29-degree acme-type thread.

Ground Thread Taps

All commercial ground thread taps made to the thread limits shown in Tables 3 and 6 will be marked with one ring on the shank near the thread in addition to the standard marking.

All precision ground thread taps made to the thread limits shown in Table 4 will be marked with the limit number. Other precision ground thread taps will be marked with the same limit number, as follows:

Taps having a P.D. between basic and minus 0.0005......	01
Taps having a P.D. between basic and plus 0.0005.......	1
Taps having a P.D. between .0005 to 0.0010 over basic...	2

Ground thread pipe taps made to Tables 8 and 9 will be marked "CG."

Other special ground thread taps will be marked CG if the pitch diameter grinding tolerance is equal to or greater than shown on page 174, and will be marked PG if it is less.

	INCHES
4 to 5 1/2 threads per inch, inclusive	0.0020
6 threads per inch	0.0018
7 threads per inch	0.0015
8 threads per inch	0.0014
9 threads per inch	0.0012
10 and 11 1/2 threads per inch	0.0011
12 threads per inch and finer	0.0010

Multiple-Thread Taps and Dies

Taps and dies having multiple threads will be marked with (1) diameter, (2) number of threads to the inch, (3) form of thread, (4) lead designated in fractions, and (5) double, triple, or quadruple.

EXAMPLE.—A 1-inch, 16 double-thread special tap with American National form of thread will be marked as follows:

1″-16 NS
1/8 Lead Double

The same tap with acme thread will be marked as follows:

1″-16 Acme
1/8 Lead Double

American Standard Thread Series

The American Standard coarse thread series includes the following sizes and pitches:

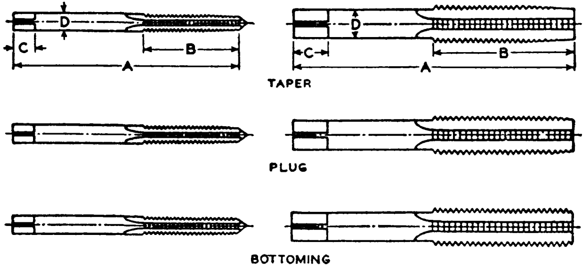
No. 1-64 NC
No. 2-56 NC
No. 3-48 NC
No. 4-40 NC
No. 5-40 NC
No. 6-32 NC
No. 8-32 NC
No. 10-24 NC
No. 12-24 NC
1/4″ -20 NC
5/16″-18 NC
3/8″ -16 NC
7/16″-14 NC
1/2″ -13 NC
9/16″-12 NC
5/8 - NC
3/4″ -10 NC
7/8″-9 NC
1″ -8 NC
1 1/8″-7 NC
1 1/4″-7 NC
1 3/8″-6 NC
1 1/2″-6 NC
1 3/4″-5 NC
2″ -4 1/2 NC
2 1/4″-4 1/2 NC
2 1/2″-4 NC
2 3/4″-4 NC
3″ -4 NC
3 1/4″-4 NC
3 1/2″-4 NC
3 3/4″-4 NC
4″-4 NC

The American Standard fine thread series includes the following sizes and pitches:

No. 0-80 NF
No. 1-72 NF
No. 2-64 NF
No. 3-56 NF
No. 4-48 NF
No. 5-44 NF
No. 6-40 NF
No. 8-36 NF
No. 10-32 NF
No. 12-28 NF
1/4″ -28 NF
5/16″-24 NF
3/8″ -24 NF
7/16″-20 NF
1/2″ -20 NF
9/16″-18 NF
5/8″ -18 NF
3/4″ -16 NF
7/8″ -14 NF
1″ -14 NF
1 1/8″ -12 NF
1 1/4″ -12 NF
1 3/8″ -12 NF
1 1/2″ -12 NF

The American Standard for screw threads includes also an 8-pitch, 12-pitch, and 16-pitch series.

TABLE 1.—REGULAR HAND TAPS, FORMERLY CALLED "STANDARD"
Carbon steel—cut thread—high-speed steel—cut thread—high-speed steel—commercial ground thread—high-speed steel—precision ground thread



GENERAL DIMENSIONS OF TAPS AVAILABLE

Diameter of Tap	Threads per Inch						Number of Flutes	Dimensions			Diameter of Shank	Size of Square
	Carbon Steel			High-Speed Steel				Length Over All	Length of Full Thread	Length of Square		
	NC*	NF*	NS*	NC	NF	NS		A	B	C	D	E
$\frac{1}{16}$	...	..	64	..	..	.....	3	$1\frac{5}{8}$	$\frac{5}{16}$	$\frac{3}{16}$	0.141	0.110
$\frac{3}{32}$	...	..	48	..	..	..	3	$1\frac{3}{4}$	$\frac{7}{16}$	$\frac{3}{16}$	0.141	0.110
$\frac{1}{8}$	...	..	40	..	..	.....	3	$1\frac{15}{16}$	$\frac{5}{8}$	$\frac{3}{16}$	0.141	0.110
$\frac{5}{32}$	...	..	32, 36	..	..	.....	4	$2\frac{1}{16}$	$\frac{3}{4}$	$\frac{1}{4}$	0.160	0.125
$\frac{3}{16}$	...	..	24, 32	..	..	.. .	4	$2\frac{3}{8}$	$\frac{7}{8}$	$\frac{1}{4}$	0.192	0.149

TABLE 1.—REGULAR HAND TAPS, FORMERLY CALLED "STANDARD."—*Continued*

Diameter of Tap	Threads per Inch						Number of Flutes	Dimensions			Diameter of Shank	Size of Square
	Carbon Steel			High-Speed Steel				Length Over All	Length of Full Thread	Length of Square		
	NC*	NF*	NS*	NC	NF	NS		A	B	C	D	E
7/32	...	..	24, 32	..	..	.....	4	2 3/8	15/16	1/4	0.223	0.167
1/4	20	28	24, 27, 32	20	28	.....	4	2 1/2	1	9/32	0.255	0.119
5/16	18	24	20, 27, 32	18	24	.....	4	2 23/32	1 1/8	5/16	0.318	0.238
3/8	16	24	20, 27	16	24	.....	4	2 15/16	1 1/4	3/8	0.381	0.286
7/16	14	20	24, 27	14	20	.....	4	3 5/32	1 7/16	13/32	0.323	0.242
1/2	13	20	12, 24, 27	13	20	.....	4	3 3/8	1 21/32	7/16	0.367	0.275
9/16	12	18	27	12	18	.....	4	3 19/32	1 21/32	1/2	0.429	0.322
5/8	11	18	12, 27	11	18	.....	4	3 13/16	1 13/16	9/16	0.480	0.360
11/16	...	..	11, 16	..	..	11, 16	4	4 1/32	1 13/16	5/8	0.542	0.406
3/4	10	16	12, 27	10	16	.....	4	4 1/4	2	11/16	0.590	0.442
7/8	9	14	12, 27	9	14	.....	4	4 11/16	2 7/32	3/4	0.697	0.523
1	8	14	12, 27	8	14	.....	4	5 1/8	2 1/2	13/16	0.800	0.600
1 1/8	7	12	....	7	12	.....	4	5 7/16	2 9/16	7/8	0.896	0.672
1 1/4	7	12	....	7	12	.....	4	5 3/4	2 9/16	1	1.021	0.766
1 3/8	6	12	....	6	12	.....	4	6 1/16	3	1 1/16	1.108	0.831
1 1/2	6	12	....	6	12	.....	4	6 3/8	3	1 1/8	1.233	0.925
1 5/8	...	..	5 1/2	..	..	.....	6	6 11/16	3 3/16	1 1/8	1.305	0.979
1 3/4	5	..	....	..	..	.....	6	7	3 3/16	1 1/4	1.430	1.072
1 7/8	...	..	5	..	..	.....	6	7 5/16	3 9/16	1 1/4	1.519	1.139
2	4 1/2	..	....	..	..	.....	6	7 5/8	3 9/16	1 3/8	1.644	1.233

All dimensions are given in inches.
* NC = coarse threads; NF = fine; NS = special.

TABLE 2.—TOLERANCES

Element	Range	Direction	Tolerance	
			Cut Thread	Ground Thread
Length over all (A).....	1/16 to 1 incl.	Plus or minus	1/32	1/32
	1 1/8 to 2 incl.	Plus or minus	1/16	1/16
Length of thread (B)...	1/16 to 7/32 incl.	Plus or minus	3/64	3/64
	1/4 to 1/2 incl.	Plus or minus	1/16	1/16
	9/16 to 1 1/2 incl.	Plus or minus	3/32	3/32
	1 5/8 to 2 incl.	Plus or minus	1/8	1/8
Length of square (C)...	1/16 to 1 incl.	Plus or minus	1/32	1/32
	1 1/8 to 2 incl.	Plus or minus	1/16	1/16
Diameter of shank (D).	1/16 to 7/32 incl.	Minus	0.004	0.0015
	1/4 to 5/8 incl.	Minus	0.005	0.0015
	11/16 to 1 incl.	Minus	0.005	0.002
	1 1/8 to 1 1/2 incl.	Minus	0.007	0.002
	1 5/8 to 2 incl.	Minus	0.007	0.003
Size of square (E)......	1/16 to 1/2 incl.	Minus	0.004	0.004
	9/16 to 1 incl.	Minus	0.006	0.006
	1 1/8 to 2 incl.	Minus	0.008	0.008

All dimensions are given in inches.

These taps are furnished with American National form of thread in taper, plug or bottoming style, except where so stated.

Cut thread taps will be furnished unless ground thread taps are specified.

Cut thread taps up to 9/16 inch inclusive have external center on thread end; sizes 5/8 inch and larger have internal center in thread end.

All ground thread taps 1/4 inch and larger have internal center in thread end.

Machine screw taps are recommended for sizes under 1/4 inch.

Sizes and dimensions not listed are special.

Left-hand taps are special.

Lead Tolerance

Cut threads, ±0.003 inch per inch of thread.
Ground threads, ±0.0005 inch per inch of thread.

Angle Tolerance—Cut Threads

Threads per Inch	Error in Half-Angle	Error in Full Angle
4½ to 5½	±35′	53′
6 to 9	±40′	60′
10 to 28	±45′	68′
30 to 64	±60′	90′

Angle Tolerance—Ground Threads

Threads per Inch	Error in Half-Angle
6 to 9	±25′
10 to 28	±30′

TABLE 3.—HAND TAPS, CUT THREAD, AND HAND TAPS, COMMERCIAL GROUND THREAD—NATIONAL FORM

Size	Threads per Inch		Major Diameter			Pitch Diameter			Size	Threads per Inch		Major Diameter			Pitch Diameter		
	NC	NF	Basic	Minimum	Maximum	Basic	Minimum	Maximum		NC	NF	Basic	Minimum	Maximum	Basic	Minimum	Maximum
¼	20	..	0.2500	0.2532	0.2557	0.2175	0.2180	0.2200	¼	20	..	0.2500	0.2540	0.2550	0.2175	0.2180	0.2190
¼	..	28	0.2500	0.2524	0.2549	0.2268	0.2273	0.2288	¼	..	28	0.2500	0.2525	0.2535	0.2268	0.2273	0.2283
5/16	18	..	0.3125	0.3160	0.3185	0.2764	0.2769	0.2789	5/16	18	..	0.3125	0.3170	0.3180	0.2764	0.2679	0.2779
5/16	..	24	0.3125	0.3153	0.3178	0.2854	0.2859	0.2874	5/16	..	24	0.3125	0.3155	0.3165	0.2854	0.2859	0.2869
⅜	16	..	0.3750	0.3789	0.3814	0.3344	0.3349	0.3369	⅜	16	..	0.3750	0.3800	0.3810	0.3344	0.3349	0.3359
⅜	..	24	0.3750	0.3778	0.3803	0.3479	0.3484	0.3499	⅜	..	24	0.3750	0.3780	0.3790	0.3479	0.3484	0.3494
7/16	14	..	0.4375	0.4419	0.4449	0.3911	0.3916	0.3941	7/16	14	..	0.4375	0.4435	0.4445	0.3911	0.3916	0.3926
7/16	..	20	0.4375	0.4407	0.4437	0.4050	0.4055	0.4075	7/16	..	20	0.4375	0.4415	0.4425	0.4050	0.4055	0.4065
½	13	..	0.5000	0.5047	0.5077	0.4500	0.4505	0.4530	½	13	..	0.5000	0.5065	0.5075	0.4500	0.4505	0.4515
½	..	20	0.5000	0.5032	0.5062	0.4675	0.4680	0.4700	½	..	20	0.5000	0.5040	0.5050	0.4675	0.4680	0.4690
9/16	12	..	0.5625	0.5675	0.5705	0.5084	0.5089	0.5114	9/16	12	..	0.5625	0.5690	0.5700	0.5084	0.5089	0.5099
9/16	..	18	0.5625	0.5660	0.5690	0.5264	0.5269	0.5289	9/16	..	18	0.5625	0.5670	0.5680	0.5264	0.5269	0.5279
⅝	11	..	0.6250	0.6304	0.6334	0.5660	0.5665	0.5690	⅝	11	..	0.6250	0.6320	0.6330	0.5660	0.5665	0.5676
⅝	..	18	0.6250	0.6285	0.6315	0.5889	0.5894	0.5914	⅝	..	18	0.6250	0.6295	0.6305	0.5889	0.5894	0.5904
¾	10	..	0.7500	0.7559	0.7599	0.6850	0.6855	0.6885	¾	10	..	0.7500	0.7575	0.7590	0.6850	0.6855	0.6866
⅞	9	..	0.8750	0.8820	0.8860	0.8028	0.8038	0.8068	¾	..	16	0.7500	0.7550	0.7560	0.7094	0.7099	0.7109
1	8	..	1.0000	1.0078	1.0118	0.9188	0.9198	0.9228	⅞	9	..	0.8750	0.8835	0.8850	0.8028	0.8038	0.8050
1	..	14	1.0000	1.0049	1.0089	0.9536	0.9546	0.9571	⅞	..	14	0.8750	0.8810	0.8820	0.8286	0.8296	0.8306
1⅛	7	..	1.1250	1.1337	0.1382	1.0322	1.0332	1.0367	1	8	..	1.0000	1.0095	1.0110	0.9188	0.9198	0.9212
1⅛	..	12	1.1250	1.1305	1.1350	1.0709	1.0719	0.0749	1	..	14	1.0000	1.0060	1.0070	0.9536	0.9546	0.9556
1¼	7	..	1.2500	1.2587	1.2632	1.1572	1.1582	1.1617	1⅛	7	..	1.1250	1.1350	1.1370	1.0322	1.0332	1.0347
1¼	..	12	1.2500	1.2555	1.2600	1.1959	1.1969	1.1999	1⅛	..	12	1.1250	1.1315	1.1325	1.0709	1.0719	0.0729
1⅜	6	..	1.3750	1.3850	1.3895	1.2667	1.2677	1.2712	1¼	7	..	1.2500	1.2600	1.2620	1.1572	1.1582	1.1597
1⅜	..	12	1.3750	1.3805	1.3850	1.3209	1.3219	1.3249	1¼	..	12	1.2500	1.2565	1.2575	1.1959	1.1969	1.1979
1½	6	..	1.5000	1.5100	1.5145	1.3917	1.3927	1.3962	1⅜	6	..	1.3750	1.3870	1.3890	1.2667	1.2677	1.2695
1½	..	12	1.5000	1.5055	1.5100	1.4459	1.4469	1.4499	1⅜	..	12	1.3750	1.3815	1.3825	1.3209	1.3219	1.3229
1¾	5	..	1.7500	1.7602	1.7657	1.6201	1.6216	1.6256	1½	6	..	1.5000	1.5121	1.5140	1.3917	1.3927	1.3945
2	4½	..	2.0000	2.0111	2.0166	1.8557	1.8572	1.8612	1½	..	12	1.5000	1.5065	1.5075	1.4459	1.4469	1.4479

TABLE 4.—HAND TAPS, PRECISION GROUND THREAD—NATIONAL FORM

Size	Threads per Inch			Major Diameter		Basic Pitch Diam.	Pitch Diameter Limits				
							01 Limit	1 Limit	2 Limit	3 Limit	
	NC	NF	NS	Minimum	Maximum		Minimum 01	Max. 01 Min. 1	Max. 1 Min. 2	Max. 2 Min. 3	Maximum 3
1/4	20	..	..	0.2540	0.2550	0.2175	0.2170	0.2175	0.2180	0.2185	0.2190
1/4	..	28	..	0.2525	0.2535	0.2268	......	0.2268	0.2273	0.2278	0.2283
5/16	18	..	..	0.3170	0.3180	0.2764	0.2759	0.2764	0.2769	0.2774	0.2779
5/16	..	24	..	0.3155	0.3165	0.2854	......	0.2854	0.2859	0.2864	0.2869
3/8	16	..	..	0.3800	0.3810	0.3344	0.3339	0.3344	0.3349	0.3354	0.3359
3/8	..	24	..	0.3780	0.3790	0.3479	......	0.3479	0.3484	0.3489	0.3494
7/16	14	..	..	0.4435	0.4445	0.3911	0.3906	0.3911	0.3916	0.3921	0.3926
7/16	..	20	..	0.4415	0.4425	0.4050	......	0.4050	0.4055	0.4060	0.4065
1/2	13	..	..	0.5065	0.5075	0.4500	0.4495	0.4500	0.4505	0.4510	0.4515
1/2	..	20	..	0.5040	0.5050	0.4675	......	0.4675	0.4680	0.4685	0.4690
9/16	12	..	..	0.5690	0.5700	0.5084	......	0.5084	0.5089	0.5094	0.5099
9/16	..	18	..	0.5670	0.5680	0.5264	......	0.5264	0.5269	0.5274	0.5279
5/8	11	..	..	0.6320	0.6330	0.5660	......	0.5660	0.5665	0.5670	0.5675
5/8	..	18	..	0.6295	0.6305	0.5889	......	0.5889	0.5894	0.5899	0.5904
3/4	10	..	..	0.7575	0.7590	0.6850	......	0.6850	0.6855	0.6860	0.6865
3/4	..	16	..	0.7550	0.7560	0.7094	......	0.7094	0.7099	0.7104	0.7109
7/8	9	..	..	0.8835	0.8850	0.8028	....	0.8028	0.8033	0.8038	0.8043
7/8	..	14	..	0.8810	0.8820	0.8286	.....	0.8286	.8291	0.8296	0.8301
1	8	..	..	1.0095	1.0110	0.9188	......	0.9188	0.9193	0.9198	0.9203
1	..	14	..	1.0060	1.0070	0.9536	......	0.9536	0.9541	0.9546	0.9551

Lead Tolerance

A maximum lead error of ±0.0005 inch in 1 inch of thread is permitted.

Angle Tolerance

8 to 9 threads per inch = ±25 minutes in half-angle.
10 to 28 threads per inch = ±30 minutes in half-angle.

HAND TAP SHANKS

Tap Diameter	Shank Diameter	Size of Square	Length of Square, in Inches	Tap Diameter	Shank Diameter	Size of Square	Length of Square, in Inches
1/16 3/32 1/8	0.141	0.110	3/16	11/16	0.542	0.406	5/8
				3/4	0.590	0.442	11/16
				7/8	0.697	0.523	3/4
5/32	0.160	0.125	1/4	1	0.800	0.600	13/16
3/16	0.192	0.149	1/4	1 1/8	0.896	0.672	7/8
7/32	0.223	0.167	1/4	1 1/4	1.021	0.766	1
1/4	0.255	0.191	9/32	1 3/8	1.108	0.831	1 1/16
5/16	0.318	0.238	5/16	1 1/2	1.233	0.925	1 1/8
3/8	0.381	0.286	3/8	1 5/8	1.305	0.979	1 3/16
7/16	0.325	0.242	11/32	1 3/4	1.430	1.072	1 1/4
1/2	0.367	0.275	7/16	1 7/8	1.519	1.139	1 5/16
9/16	0.429	0.322	1/2	2	1.644	1.233	1 3/8
5/8	0.480	0.360	9/16				

TABLE 5.—MACHINE SCREW TAPS
Cut Thread—American National Form
Thread Limits

Screw Gage Number	Threads per Inch			Major Diameter, in Inches			Pitch Diameter, in Inches		
	NC	NF	NS	Basic	Min.	Max.	Basic	Min.	Max.
0	..	..	80	0.0600	0.0609	0.0624	0.0519	0.0521	0.0531
1	..	..	56	0.0730	0.0742	0.0757	0.0614	0.0616	0.0626
1	64	..	..	0.0730	0.0740	0.0755	0.0629	0.0631	0.0641
1	..	72	..	0.0730	0.0740	0.0755	0.0640	0.0642	0.0652
2	56	..	..	0.0860	0.0872	0.0887	0.0744	0.0746	0.0756
2	..	64	..	0.0860	0.0870	0.0885	0.0759	0.0761	0.0771
3	48	..	..	0.0990	0.1003	0.1018	0.0855	0.0857	0.0867
3	..	56	..	0.0990	0.1002	0.1017	0.0874	0.0876	0.0886
4	..	..	32	0.1120	0.1142	0.1162	0.0917	0.0922	0.0937
4	..	..	36	0.1120	0.1137	0.1157	0.0940	0.0942	0.0957
4	40	..	..	0.1120	0.1136	0.1156	0.0958	0.0960	0.0975
4	..	48	..	0.1120	0.1133	0.1153	0.0985	0.0987	0.1002
5	40	..	..	0.1250	0.1266	0.1286	0.1088	0.1090	0.1105
5	..	44	..	0.1250	0.1264	0.1284	0.1102	0.1104	0.1119
6	32	..	..	0.1380	0.1402	0.1422	0.1177	0.1182	0.1197
6	..	..	36	0.1380	0.1397	0.1417	0.1200	0.1202	0.1217
6	..	40	..	0.1380	0.1396	0.1416	0.1218	0.1220	0.1235
8	32	..	..	0.1640	0.1662	0.1682	0.1437	0.1442	0.1457
8	..	36	..	0.1640	0.1657	0.1677	0.1460	0.1462	0.1477
8	..	..	40	0.1640	0.1656	0.1676	0.1478	0.1480	0.1495
10	24	..	..	0.1900	0.1928	0.1948	0.1629	0.1634	0.1649
10	..	..	30	0.1900	0.1923	0.1943	0.1684	0.1689	0.1704
10	..	32	..	0.1900	0.1922	0.1942	0.1697	0.1702	0.1717
12	24	..	..	0.2160	0.2188	0.2208	0.1889	0.1894	0.1909
12	..	28	..	0.2160	0.2184	0.2204	0.1928	0.1933	0.1948
12	..	..	32	0.2160	0.2182	0.2202	0.1957	0.1962	0.1977
14	..	..	20	0.2420	0.2452	0.2477	0.2095	0.2100	0.2120
14	..	..	24	0.2420	0.2448	0.2473	0.2149	0.2154	0.2174

MACHINE SCREW TAP SHANKS

Screw Gage Number	Shank Diameter	Square	
		Size	Length, in Inches
3 4 5 6	0.141	0.110	$\frac{3}{16}$
8	0.168	0.131	$\frac{1}{4}$
10	0.194	0.152	$\frac{1}{4}$
12	0.220	0.165	$\frac{9}{32}$
14	0.247	0.185	$\frac{9}{32}$

TABLE 6.—MACHINE SCREW TAPS
Commercial Ground Thread—American National Form
Thread Limits

Screw Gage Number	Threads per Inch			Major Diameter, in Inches			Pitch Diameter, in Inches		
	NC	NF	NS	Basic	Min.	Max.	Basic	Min.	Max.
3	48	..	..	0.0990	0.1000	0.1010	0.0855	0.0857	0.0867
3	..	56	..	0.0990	0.0995	0.1005	0.0874	0.0876	0.0886
4	..	..	36	0.1120	0.1135	0.1145	0.0940	0.0942	0.0952
4	40	..	..	0.1120	0.1135	0.1145	0.0958	0.0960	0.0970
4	..	48	..	0.1120	0.1130	0.1140	0.0985	0.0987	0.0997
5	40	..	..	0.1250	0.1265	0.1275	0.1088	0.1090	0.1100
5	..	44	..	0.1250	0.1260	0.1270	0.1102	0.1104	0.1114
6	32	..	..	0.1380	0.1400	0.1410	0.1177	0.1182	0.1192
6	..	40	..	0.1380	0.1395	0.1405	0.1218	0.1220	0.1230
8	32	..	..	0.1640	0.1660	0.1670	0.1437	0.1442	0.1452
8	..	36	..	0.1640	0.1655	0.1665	0.1460	0.1462	0.1472
10	24	..	..	0.1900	0.1930	0.1940	0.1629	0.1634	0.1644
10	..	32	..	0.1900	0.1920	0.1930	0.1697	0.1702	0.1712
12	24	..	..	0.2160	0.2190	0.2200	0.1889	0.1894	0.1904
12	..	28	..	0.2160	0.2185	0.2195	0.1928	0.1933	0.1943
14	..	..	20	0.2420	0.2460	0.2470	0.2095	0.2100	0.2110
14	..	..	24	0.2420	0.2450	0.2460	0.2149	0.2154	0.2164

Lead tolerances are the same as for hand taps.

Angle Tolerance—Cut Thread

20 to 28 (incl.) threads per inch = ±45 minutes in half-angle = ±68 minutes in full angle.

30 threads per inch and finer = ±60 minutes in half-angle = ±90 minutes in full angle.

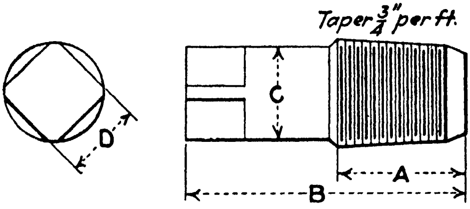
Angle Tolerance—Ground Thread

20 to 56 (incl.) threads per inch = ±30 minutes in half-angle.

Pulley taps, nut taps, and staybolt taps are made with approximately the same tolerances as hand taps.

The size of a tapped hole, however, is affected by the material, by the way the tap is ground, by whether it is dull or sharp, and by the lubricant used. A heavy oil will make a tap cut oversize. This is sometimes used to compensate for the shrinkage of a tapped hole in hardening. Bakelite and other plastic material usually closes in after the tap is withdrawn.

Table 7.—Dimensions of Pipe Taps



Nominal Sizes Inches	Length, Inches		Diam. of Shank Inches *C*	Size of Square Inches *D*	Distance Small End of Briggs Standard Tap Projects through Gage	Pitch Diam. of Straight Pipe Tap, Inches		
	Thread *A*	Over-all *B*				Basic	Minimum	Maximum
1/8	3/4	2 1/8	0.3125 0.4375	0.234 0.328	0.312	0.3748	0.3733	0.3763
1/4	1 1/16	2 7/16	0.4375 0.5625	0.328 0.421	0.459	0.4899	0.4884	0.4914
3/8	1 1/16	2 9/16	0.5625 0.7000	0.421 0.531	0.454	0.6270	0.6253	0.6288
1/2	1 3/8	3 1/8	0.6875 0.8650	0.515 0.640	0.579	0.7784	0.7767	0.7802
5/8	1 3/8	3 3/16	0.8125 0.9270	0.594 0.687				
3/4	1 3/8	3 1/4	0.9063 1.0750	0.679 0.812	0.565	0.9889	0.9869	0.9909
7/8	1 9/16	3 1/2	1.0937	0.812				
1	1 3/4	3 3/4	1.1250	0.843	0.678	1.2386	1.2366	1.2406
1 1/4	1 3/4	4	1.3125	0.984	0.686	1.5834	1.5811	1.5856
1 1/2	1 3/4	4 1/4	1.5000	1.125	0.699	1.8223	1.8201	1.8246
1 3/4	1 3/4	4 3/8	1.6250	1.218				
2	1 3/4	4 1/2	1.8750	1.406	0.667	2.2963	2.2938	2.2988
2 1/4	2 3/8	5	2.0000	1.500				
2 1/2	2 9/16	5 1/2	2.2500	1.687	0.925	2.7622	2.7594	2.7649
2 3/4	2 9/16	5 3/4	2.3750	1.781				
3	2 5/8	6	2.6250	1.968	0.925	3.3885	3.3858	3.3913
3 1/4	2 5/8	6 1/4	2.7500	2.062				
3 1/2	2 11/16	6 1/2	2.8125	2.108	0.938	3.8888	3.8861	3.8916
3 3/4	2 11/16	6 5/8	2.8750	2.156				
4	2 3/4	6 3/4	3.0000	2.250	0.950	4.3871	4.3844	4.3899

For thread diameters see Cols. *A* and *B*, Table I, p. 96 and p. 150.

Tolerances

Length overall, 1/8 to 3/4 inch inclusive	Plus or minus 1/32 inch
Length overall, 7/8 to 4 inches inclusive	Plus or minus 1/16 inch
Length of thread	Plus or minus 3/64 inch
Diameter of shank to 1/2 inch inclusive	Size to size minus 0.007 inch
Diameter of shank over 1/2 inch	Size to size minus 0.009 inch
Size of square to 1/2 inch inclusive	Size to size minus 0.006 inch
Size of square over 1/2 inch	Size to size minus 0.010 inch
Distance projecting through gage, 1/8 to 3/4 inch inclusive	Plus or minus 1/16 inch
Distance projecting through gage, 1 to 3 inches inclusive	Plus or minus 3/32 inch
Distance projecting through gage, 3 1/2 inches and over	Plus or minus 1/8 inch

TABLE 8.—PIPE TAP TOLERANCES—CUT AND GROUND THREADS

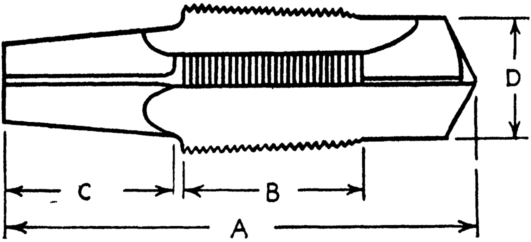
Nominal Size in Inches	Threads per Inch N.P.T.	Gage Measurement* Projection Tolerance Plus or Minus		Lead Tolerance per Inch of Thread Plus or Minus		Angle Tolerance in Minutes Half Angle Plus or Minus		Angle Tolerance in Minutes Full Angle	Taper per Foot Plus or Minus	
		Cut Thread	Ground Thread	Cut Thread	Ground Thread	Cut Thread	Ground Thread	Cut Thread	Cut Thread	Ground Thread
1/8	27	1/16	1/16	0.003	0.0005	45	30	68	1/16	1/32
1/4	18	1/16	1/16	0.003	0.0005	45	30	68	1/16	1/32
3/8	18	1/16	1/16	0.003	0.0005	45	30	68	1/16	1/32
1/2	14	1/16	1/16	0.003	0.0005	45	30	68	1/16	1/32
3/4	14	1/16	1/16	0.003	0.0005	45	30	68	1/16	1/32
1	11½	3/32	3/32	0.003	0.0005	45	30	68	1/16	1/32
1¼	11½	3/32	3/32	0.003	0.0005	45	30	68	1/16	1/32
1½	11½	3/32	3/32	0.003	0.0005	45	30	68	1/16	1/32
2	11½	3/32	3/32	0.003	0.0005	45	30	68	1/16	1/32
2½	8	3/32	3/32	0.003	0.0005	40	25	60	1/16	1/32
3	8	3/32	3/32	0.003	0.0005	40	25	60	1/16	1/32
3½	8	1/8	1/8	0.003	0.0005	40	25	60	1/16	1/32
4	8	1/8	1/8	0.003	0.0005	40	25	60	1/16	1/32

* For basic distance small end of tap should project through American Standard ring gage. See table on p. 149.

TABLE 9.—PIPE TAP DIAMETER AT GAGE POINT

Pipe Size	Diameter at Gage Point Basic	Distance of Gage Point from End of Tap	Tolerance Plus or Minus	Pipe Size	Diameter at Gage Point Basic	Distance of Gage Point from End of Tap	Tolerance Plus or Minus
1/8	0.36351	0.312	1/16	1½	1,79609	0.699	3/32
1/4	0.47739	0.459	1/16	2	2.26902	0.667	3/32
3/8	0.61201	0.454	1/16	2½	2.71953	0.925	3/32
1/2	0.75843	0.579	1/16	3	3.34063	0.925	3/32
3/4	0.96768	0.565	1/16	3½	3.83750	0.938	1/8
1	1.21363	0.678	3/32	4	4.33438	0.950	1/8
1¼	1.55713	0.686	3/32				

TABLE 10.—COMBINED PIPE TAP AND DRILL, CARBON STEEL—CUT THREAD



These taps are furnished with American Standard form of thread.
The shanks are the standard drill size taper square shanks.
Sizes and dimensions not listed are special.
Left-hand taps are special.

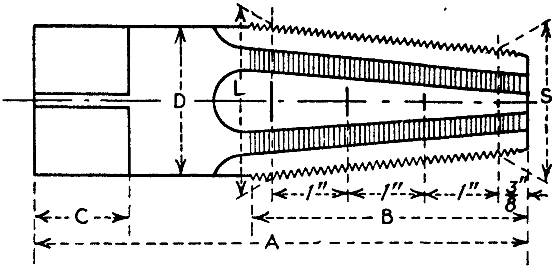
Nominal Size in Inches	Threads per Inch	Dimensions in Inches						
		Length Over-all A	Length of Full Thread B	Length of Square C	Size Square		Drill Diameter D	
					Small End	Large End	Size	Decimal Equivalent
1/8	27	Manufacturers individual practice	3/4	1 [illegible]	[illegible]	[illegible]	R	0.339
1/4	18		1 1/16	1 [illegible]	[illegible]	[illegible]	7/16	0.437
3/8	18		1 1/16	1 [illegible]	[illegible]	[illegible]	37/64	0.578
1/2	14		1 [illegible]	1 [illegible]	[illegible]	[illegible]	23/32	0.719
3/4	14		1 [illegible]	1 [illegible]	[illegible]	[illegible]	59/64	0.921
1	11 1/2		1 [illegible]	1 [illegible]	[illegible]	[illegible]	1 5/32	1.156
1 1/4	11 1/2		1 [illegible]	1 [illegible]	[illegible]	[illegible]	1 1/2	1.500
1 1/2	11 1/2		1 [illegible]	1 [illegible]	[illegible]	[illegible]	1 47/64	1.734
2	11 1/2		1 [illegible]	2	[illegible]	1	2 7/32	2.218

Tolerances

Element	Range, Nominal Size in Inches	Direction	Tolerance in Inches
Length overall—A	1/8 to 2 incl.	Plus or minus	1/16
Length of thread—B	1/8 to 3/4 incl. 1 and 1 1/4 1 1/2 and 2	Plus or minus Plus or minus Plus or minus	1/16 3/32 1/8
Gage measurement*	1/8 to 3/4 incl. 1 to 2 incl.	Plus or minus Plus or minus	1/16 3/32

* Distance small end of tap projects through American Standard ring gage.

TABLE 11.—MUD OR WASHOUT TAPS, CARBON STEEL—CUT THREAD



These taps are furnished with National or V form of thread.

Mud or washout taps are regularly furnished with a taper of 1½ inches to the foot and are marked to correspond with taper plugs bearing the same numbers.

All taps have internal center in thread end.

Sizes and dimensions not listed are special.

Left-hand taps are special.

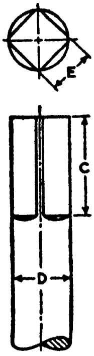
Tap Number	Threads per Inch	No. of Flutes	Dimensions in Inches						
			Length Overall	Length of Full Thread	Length of Square	Diam. of Shank	Size of Square	Diameter	
								Small End	Large End
			A	B	C	D	E	S	L
1	12	6	6½	3⅜	1¼	2	1½	1¾	2 3/16
2	12	6	6½	3⅜	1¼	2	1½	2 1/16	2½
3	12	8	6½	3⅜	1¼	2	1½	2⅜	2 13/16
4	12	8	6½	3⅜	1¼	2	1½	2 9/16	3
5	12	8	6½	3⅜	1¼	3	1½	3	3 7/16

Tolerances

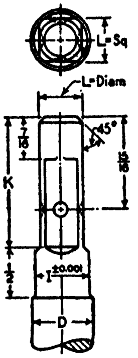
Element	Range, Tap Number	Direction	Tolerance in Inches
Length overall—A	1 to 5 incl.	Plus or minus	1/32
Length of thread—B	1 to 5 incl.	Plus or minus	1/32
Length of square—C	1 to 5 incl.	Plus or minus	1/16
Diameter of shank—D	1 to 5 incl.	Minus	0.007
Size of square—E	1 to 5 incl.	Minus	0.008

TABLE 12.—TAPPER TAP SHANKS

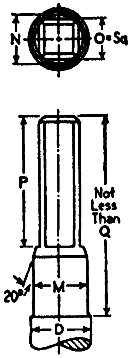
General Dimensions



PLAIN ROUND OR SQUARED



ACME IMPROVED TYPE "C"



NATIONAL INTERCHANGEABLE RING LOCK

Diameter of Tap, in Inches	Dimensions, in Inches										
	C	*D*	*E*	*I*	*K*	*L*	*M*	*N*	*O*	*P*	*Q*
1/4	9/16	0.185	0.139	0.177	1 5/16	0.147	0.185	0.170	0.134	11/16	2 1/2
5/16	5/8	0.240	0.180	0.232	1 5/16	0.188	0.240	0.221	0.165	11/16	2 1/2
3/8	11/16	0.294	0.220	0.286	1 5/16	0.240	0.290	0.271	0.208	11/16	2 1/2
7/16	3/4	0.345	0.259	0.336	1 5/16	0.290	0.340	0.320	0.240	11/16	2 1/2
1/2	7/8	0.400	0.300	0.390	1 5/16	0.320	0.400	0.374	0.286	1	3 1/4
9/16	7/8	0.450	0.337	0.446	1 5/16	0.350	0.450	0.422	0.318	1	3 1/4
5/8	15/16	0.503	0.377	0.500	1 5/16	0.390	0.500	0.450	0.350	1	3 1/4
3/4	1	0.616	0.462	0.610	1 5/16	0.480	0.615	0.540	0.422	1 1/16	3 1/4
7/8	1 1/16	0.727	0.545	0.722	1 5/16	0.540	0.720	0.630	0.500	1 1/16	3 1/4
1	1 1/8	0.834	0.625	0.829	1 3/8	0.650	0.825	0.730	0.574	1 1/16	3 7/8
1 1/8	1 1/4	0.933	0.700	0.929	1 3/8	0.710	0.930	0.855	0.667	1 1/4	4 1/4
1 1/4	1 5/16	1.058	0.793	1.053	1 3/8	0.780	1.055	0.975	0.760	1 1/4	4 1/4
1 3/8	1 3/8	1.153	0.865	1.149	1 3/8	0.850	1.150	1.055	0.824	1 1/4	4 1/4
1 1/2	1 1/2	1.278	0.958	1.269	1 3/8	0.950	1.275	1.195	0.917	1 1/4	4 1/4

Tolerances

Element	Range, in Inches	Direction	Tolerance, in Inches	
			Cut Thread	Ground Thread
Length of square........	1/4 to 3/4 incl.	Plus or minus	1/32	1/32
	7/8 to 1 1/2 incl.	Plus or minus	1/64	1/64
Size of square...........	1/4 to 1/2 incl.	Minus	0.004	0.004
	9/16 to 1 incl.	Minus	0.006	0.006
	1 1/8 to 1 1/2 incl.	Minus	0.008	0.008

THREADING SPEEDS

Threading speeds depend on many factors. Kind of material, depth of hole, cutting rake and relief of tap, chip room in the flutes, and the lubricant all play a part. Experiments have shown that the speed of taps affects the size of hole as well as the life of the tap. In one case, changing the speed and the lubricant made a variation of 0.0029 inch on a ¼–20 tap.

Material also greatly affects speed and life. In one case a 5–40 high-speed tap that would run at 75 to 80 surface feet per minute in cast iron was reduced to 26 feet in a tough material. This increased the life from 30 to 40 times.

Chamfer on Dies

All standard dies are chamfered approximately as shown in the following table.

TABLE 13.—APPROXIMATE NUMBER OF THREADS CHAMFER

Type of Die	Front Face	Rear Face
Spring screw threading	2½–3	
Solid square bolt	2½–3	1–1½
Solid square pipe	2½–3	0
Adjustable round split, straight thread	2½–3	1–1½
Adjustable round split, taper thread	2½–3	0
Gas fixture	2½–3	1–1½
Hexagon rethreading	1	1

Threads on Studs

The fitting of the fixed ends of threaded studs has been given much attention, especially by builders of automobile engines. Studs are usually threaded with the American Standard pitches on the end that screws into the cylinder block, or the fixed end, but frequently have the finer threads for the nut. With two diameters engaged in the work, the stud will usually break before it will pull out. In order to ensure that the stud is a tight fit in the hole, so that it will not unscrew when removing the nut from the stud, the fixed end is frequently made slightly oversize in order to make it a force fit.

Several large users make the fixed end of the stud with thread of 55 degrees instead of 60, and slightly oversize. The metal in the stud flows slightly into the 60-degree angle and makes a very tight fit. This practice also permits a greater variation in thread diameter and at the same time secures a better fit than is usually possible where both threads are of the same angle. Although this method gives a better fit, the stud can be backed out without tearing the metal in the hole.

Experiments have also been made with studs cut to a lead that was slightly off standard. This also forces the threads to flow in the tapped hole. The use of the 55-degree angle in the thread on the stud is much easier to obtain and gives equally good results.

Stud Fits

The accompanying tables show the accepted allowance in both cast iron and aluminum. The tapped-hole pitch diameter in columns 4 and 5 are Class IV fits.

TABLE 14.—STUD FITS IN CAST IRON

NATIONAL COARSE THREAD—NC

1	2	3	4	5	6	7	8	9
Size and Pitch	Stud		Tapped Hole		Drive		Tap	
	Pitch Diameter		Go Gage	No Go Gage	Min. Drive	Max. Drive	Pitch Diameter	
	Min.	Max.					Min.	Max.
1/4–20	0.2196	0.2203	0.2175	0.2188	0.0008	0.0028	0.2170	0.2175
5/16–18	0.2789	0.2804	0.2764	0.2779	0.0010	0.0040	0.2759	0.2764
3/8–16	0.3370	0.3389	0.3344	0.3360	0.0010	0.0045	0.3339	0.3344
7/16–14	0.3941	0.3961	0.3911	0.3929	0.0012	0.0050	0.3911	0.3916
1/2–13	0.4533	0.4555	0.4500	0 4519	0.0014	0.0055	0.4500	0.4505
9/16–12	0.5120	0.5144	0.5084	0.5104	0.0016	0.0060	0.5084	0.5089
5/8–11	0.5698	0.5720	0.5660	0.5681	0.0017	0.0060	0.5660	0.5665
3/4–10	0.6891	0.6915	0.6850	0.6873	0.0018	0.0065	0.6850	0.6855
7/8– 9	0.8071	0.8096	0.8028	0.8052	0.0019	0.0068	0.8028	0.8033
1″ – 8	0.9235	0.9260	0.9188	0.9215	0.0020	0.0072	0.9188	0.9193
1 1/8 – 7	1.0372	1.0397	1.0322	1.0352	0.0020	0.0075	1.0327	1.0337
1 1/4 – 7	1.1624	1.1649	1.1572	1.1602	0.0022	0.0077	1.1577	1.1587
1 1/2 – 6	1.3976	1.4001	1.3917	1.3953	0.0023	0.0084	1.3922	1.3932

TABLE 15.—STUD FITS IN ALUMINUM

NATIONAL COARSE THREAD—NC

1	2	3	4	5	6	7	8	9
Size and Pitch	Stud		Tapped Hole		Drive		Tap	
	Pitch Diameter		Go Gage	No Go Gage	Min. Drive	Max. Drive	Pitch Diameter	
	Min.	Max.					Min.	Max.
1/4–20	0.2216	0.2223	0.2175	0.2188	0.0028	0.0048	0.2170	0.2175
5/16–18	0.2809	0.2824	0.2764	0.2779	0.0030	0.0060	0.2759	0.2764
3/8–16	0.3390	0.3409	0.3344	0.3360	0.0030	0.0065	0.3339	0.3344
7/16–14	0.3961	0.3981	0.3911	0.3929	0.0032	0.0070	0.3911	0.3916
1/2–13	0.4553	0.4575	0.4500	0.4519	0.0034	0.0075	0.4500	0.4505
9/16–12	0.5140	0.5164	0.5084	0.5104	0.0036	0.0080	0.5084	0.5089
5/8–11	0.5718	0.5740	0.5660	0.5681	0.0037	0.0080	0.5660	0.5665
3/4–10	0.6911	0.6935	0.6850	0.6873	0.0038	0.0085	0.6850	0.6855
7/8– 9	0.8091	0.8116	0.8028	0.8052	0.0039	0.0088	0.8028	0.8033
1" – 8	0.9255	0.9280	0.9188	0.9215	0.0040	0.0092	0.9188	0.9193
1 1/8 – 7	1.0392	1.0417	1.0322	1.0352	0.0040	0.0095	1.0327	1.0337
1 1/4 – 7	1.1644	1.1669	1.1572	1.1602	0.0042	0.0097	1.1577	1.1587
1 1/2 – 6	1.3996	1.4021	1.3917	1.3953	0.0043	0.0104	1.3922	1.3932

In sizes 1/4 to 1/2 inch, tapping can usually be done in one pass. whereas 9/16 inch and larger usually require roughing and finishing taps. When roughing taps are necessary, these sizes should be as follows:

SIZE OF TAPS IN INCHES	AMOUNT ROUGHING TAP SHOULD BE BELOW BASIC P.D. SIZE IN INCHES
1/4 to 1	1/64 (0.0156)
1 and larger	1/32 (0.0312)

Watch Screw Taps

Table 16 gives all the standard taps used in connection with the screws listed by the Elgin Watch Company. The diameter in thousandths of an inch and number of threads per inch are marked on the handle of each tap.

TABLE 16.—ELGIN WATCH SCREW TAPS

Diameter of Tap		Threads per Inch	Diameter of Drill	
Inches	Millimeters		Inches	Millimeters
.0132	.33	360	.0112	.28
.0148	.37	320	.0120	.30
.0168	.42	260	.0132	.33
.0208	.52	220	.0168	.42
.0228	.57	260	.0188	.47
.0248	.62	220	.0200	.50
.0268	.67	180	.0220	.55
.0288	.72	220	.0248	.62
.0308	.77	180	.0248	.62
.0308	.77	220	.0268	.67
.0368	.92	140	.0280	.70
.0368	.92	220	.0268	.67
.0408	1.02	120L	.0300	.75
.0408	1.02	200	.0348	.87
.0428	1.07	120	.0328	.82
.0448	1.12	110	.0340	.85
.0468	1.17	110	.0348	.87
.0488	1.22	140	.0400	1.00
.0488	1.22	200	.0436	1.09
.0508	1.27	110L	.0388	.97
.0548	1.37	180	.0488	1.22
.0608	1.52	110	.0488	1.22
.0608	1.52	110L	.0488	1.22
.0708	1.77	180L	.0648	1.62
.0768	1.92	110L	.0708	1.77
.0772	1.93	80L	.0612	1.53
.0892	2.23	80L	.0712	1.78

Table 17 gives the pitch, the diameter of the thread, and also the proper size of the tap drill, for all the screws used in the Waltham Watch movements.

TABLE 17.—WALTHAM WATCH SCREW TAPS

No. of Tap	No. of Threads to an Inch	Diameter of Thread on Screws		Diameter of Drill	
		In Inches	In Millimeters	In Inches	In Millimeters
1	110	0.05906	1.50	0.05197	1.32
3	110	0.04724	1.20	0.04016	1.02
5	120	0.04331	1.10	0.03741	0.95
7	140	0.03937	1.00	0.03347	0.85
9	160	0.03661	0.93	0.02796	0.71
11	170	0.05276	1.34	0.04803	1.22
13	180	0.03937	1.00	0.03347	0.85
15	180	0.03268	0.83	0.02796	0.71
17	200	0.02560	0.65	0.02126	0.54
19	220	0.02166	0.55	0.01772	0.45
21	240	0.01772	0.45	0.01339	0.34
23	254	0.01379	0.35	0.01064	0.27

TABLE 18.—PENDANT TAPS

Size	Diameter of Tap		Threads per Inch	Diameter of Drill	
	Inches	Millimeters		Inches	Millimeters
18	.236	5.90	50	.211	5.28
16	.200	5.00	60	.180	4.50
12–6	.176	4.40	66	158	3.95
0	.156	3.90	66	.138	3.45
5/0	.128	3.20	80	.114	2.85
10/0	.103	2.58	90	.086	2.15

CROWN TAPS

Size	Diameter of Tap		Threads per Inch	Diameter of Drill	
	Inches	Millimeters		Inches	Millimeters
18	.091	2.28	60	.071	1.78
16	.077	1.93	72	.063	1.58
12–6–0	.061	1.53	80	.048	1.20
5/0–10/0	.048	1.20	110	.038	0.95

Watchmakers' Measurements

Showing the comparative values of the standards of measurements commonly used by watchmakers.

One douzième = 0.0074 inch
One millimeter = 0.03937 inch
One ligne = 0.0888 inch
One ligne = 2.256 millimeters

The Elgin Watch Company has two gages, one known as the "upright," the other as the "fine."

One degree "upright" gage = $\frac{1}{500}$ or 0.002 inch
One degree "fine" gage = $\frac{1}{2500}$ or 0.0004 inch

Button and Fastener Measurement

The button and fastener industry also uses the "ligne" as a unit of measurement, but their ligne is 0.025 inch. A 20-ligne button is ½ inch in diameter.

Table 19.—Table of Jewel Setting Diameters

Showing Their Sizes in Thousandths of an Inch and Equivalent Diameters in Millimeters

Inches	Millimeters	Inches	Millimeters	Inches	Millimeters
.054	1.37	.088	2.23	.126	3.20
.060	1.52	.092	2.33	.140	3.55
.070	1.78	.096	2.43	.144	3.65
.076	1.93	.106	2.69	.156	3.96
.080	2.03	.116	2.94	.160	4.06
.084	2.13	.122	3.09	.170	4.31
.086	2.18				

Thickness of Pallet Stones

In Thousandths of an Inch and Equivalent Thickness in Millimeters

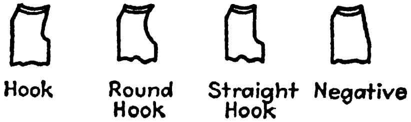
INCHES MILLIMETERS
18 and 16 Old Style (thick) 0.0168 = 0.4267
18 and 16 New Style (thin) 0.0148 = 0.3759
6 Old Style (thick) 0.0146 = 0.3708
6 New Style (thin)0.0128 = 0.3251

Tapping and Threading Speeds

In multiple machine tapping the Fox Machine Company recommends 30 feet cutting speed for cast iron and aluminum and about 18 feet for steel. A full thread is unnecessary and requires more space for chips in blind holes.

TABLE 20.—RECOMMENDED FACE GRINDS FOR DIE CHASERS

The list shows the general "face grinds" and "cutting lubricants" that have been found most satisfactory on the materials listed by the Murchey Machine & Tool Co. The different grinds are shown. It may be necessary to alter these "grinds" slightly to meet definite problems.



Material	Hobbed Chasers for Die Heads	Chasers for Taps Straight or Taper	Lubricant
Aluminum and aluminum alloys.	10-degree round hook	9-degree hook	Kerosene
Brass bar	5-degree hook	9-degree hook	Comp. or paraffin
Brass, cast	Straight	Straight	Dry
Brass, forging and stamping	9-degree hook	9-degree hook	Comp. or paraffin
Brass tubing	9-degree hook	Round hook	Comp. or paraffin
Bronze, cast	Straight	5-degree hook	Dry
Bronze rod and tubing	9-degree hook	Round hook	Comp. or paraffin
Copper	Round hook	Round hook	Comp. or paraffin
Fiber	5-degree negative	Straight	Dry
Iron, cast	Straight	Straight	Dry or with compound
Iron, malleable	5-degree hook	9-degree hook	Dry or with compound
Iron, stainless	Round hook	Round hook	Sulphur base oils
Iron, wrought	9-degree hook	9-degree hook	Sulphur base oils
Monel metal	9-degree hook	Round hook	Sulphur base oils
Pipe, cast iron	Straight	Straight	Dry or with compound
Pipe, iron and steel (tapered threads)	9-degree hook	Round hook	Sulphur base oils
Pipe, iron and steel (straight threads)	9-degree hook	Round hook	Sulphur base oils
Screw stock—Bessemer and open hearth	9-degree hook	Round hook	Sulphur base oils
Steel, carbon	9-degree hook	Round hook	Sulphur base oils
Steel, chromium	9-degree hook	Round hook	Sulphur base oils
Steel, chromium vanadium	9-degree hook	Round hook	Sulphur base oils
Steel, forgings	9-degree hook	Round hook	Sulphur base oils
Steel, nickel	9-degree hook	Round hook	Sulphur base oils
Steel, nickel chromium	9-degree hook	Round hook	Sulphur base oils
Steel, stainless	Round hook	Round hook	Sulphur base oils
Steel, tool	9-degree hook	9-degree hook	Sulphur base oils
Drawn steel tubing	9-degree hook	Round hook	Sulphur base oils
Rubber	5-degree hook	Straight	Dry

TABLE 21.—LANDIS THREADING SPEEDS
National Coarse Threads

Dia.	Materials											
	Tool Steel (Carbon)		Vanadium Steel, Nickel Steel, Forged Steel, Open Hearth, Monel Metal		Machine Steel, Drawn Steel, Tobin Bronze, Bessemer, Screw Stock		Malleable Iron, Cast Iron		Cast Brass, Bar Brass, Phosphor-Bronze, Copper		Fiber, Bakelite, Aluminum, Lead	
	R.p.m.	Surface Speed	R.p.m.	Surface Speed	R.p.m.	Surface Speed	R.p.m.	Surface Speed	R.p.m.	Surface Speed	R.p.m.	Surface Speed
1/4	306	20	535	35	764	50	917	60	1070	70	1222	80
5/16	245		428		611		733		856		978	
3/8	183	18	306	30	458	45	560	55	662	65	764	75
7/16	157		262		393		481		568		656	
1/2	137		191	25	306	40	382	50	459	60	535	70
9/16	102	15	170		272		340		407		475	
5/8	92		153		245		306		367		428	
3/4	76		102	20	178	35	229	45	279	55	330	65
7/8	65		87		153		196		241		285	
1	46	12	76		134		172		210		258	
1 1/8	41		68		119		153		187		221	
1 1/4	37		55	18	92	30	123	40	153	50	183	60
1 1/2	31		46		76		102		127		153	
1 3/4	22	10	39		66		87		109		131	
2	19		29	15	48	25	67	35	86	45	105	55
2 1/4	17		25		42		59		76		94	
2 1/2	15		23		38		53		69		84	
2 3/4	11	8	21		35		49		62		77	
3	10		13	10	26	20	38	30	51	40	64	50

TABLE 22.—LANDIS THREADING SPEEDS
National Fine Threads

Dia.	Materials											
	Tool Steel (Carbon)		Vanadium Steel, Nickel Steel, Forged Steel, Open Hearth, Monel Metal		Machine Steel, Drawn Steel, Tobin Bronze, Bessemer, Screw Stock		Malleable Iron, Cast Iron		Cast Brass, Bar Brass, Phosphor-Bronze, Copper		Fiber, Bakelite, Aluminum, Lead	
	R.p.m.	Surface Speed	R.p.m.	Surface Speed	R.p.m.	Surface Speed	R.p.m.	Surface Speed	R.p.m.	Surface Speed	R.p.m.	Surface Speed
¼	382	25	611	40	764	50	917	60	1222	80	1222	80
5/16	306		489		611		733		978		978	
⅜	255		357	35	458	45	611		815		815	
7/16	175	20	306		393		524		656	75	699	
½	153		268		344		459		573		611	
9/16	136		238		306		373	55	475	70	543	
⅝	122		214		276		337		428		489	
¾	92	18	153	30	203	40	254	50	357		381	75
⅞	79		131		153	35	219		285	65	329	
1	69		115		134		191		258		287	
1⅛	61		85	25	119		153	45	204	60	255	
1¼	46	15	76		107		137		183		214	70
1½	38		64		89		115		153		178	
1¾	33		44	20	66	30	87	40	120	55	153	
2	29		38		57		76		105		124	65
2¼	20	12	25	15	42	25	59	35	85	50	111	
2½	18		23		38		54		76		99	60
2¾	17		21		35		49		69		83	
3	15		19		32		45		64		76	

Cutting speeds listed are for annealed stock only. When heat-treated material is threaded, decrease cutting speed 20 to 30 per cent.

SECTION VI

FILES AND WORK BENCHES

FILE CHARACTERISTICS

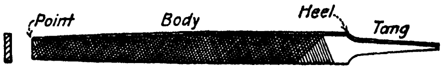
Files have three distinguishing features:

Length—measured exclusive of the tang.

Kind or name—which has reference to their shape or style; namely, flat, mill, half round, etc.

Cut—which has reference to the character and coarseness of the teeth; namely, coarse, bastard, second cut, and smooth.

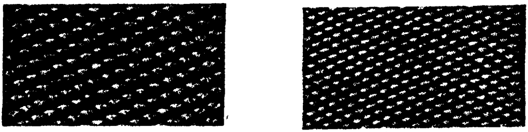
The *tang* is the sharp-pointed end of the file fitted for the handle. The *heel* is the shoulder of the file next to the tang. The *point* is the end of the file opposite the tang. The *body* is that portion of the file extending from the point to the heel. The *length* of a file is the distance between its heel and point.

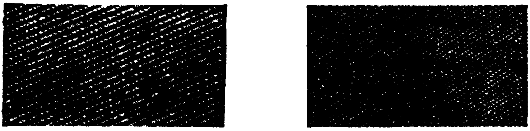


Files are made *blunt*, that is, parallel in width and thickness from point to heel, or *tapered*, that is, with the size more or less reduced in both width and thickness by a gradually narrowing section extending from one-half to two-thirds the length of the file from the point. Comparatively few blunt files are now made.

As files are tools for abrading or removing material, the arrangement and the coarseness of the teeth of which their surface is composed are of vital importance. As a general principle, files used for producing a sharp or a cutting edge on the material filed should be single cut, that is, having continuous teeth across their surface. Such teeth are also required on files used for smooth finishing or for use on surfaces that are to be polished. Most other files are required to be made double-cut, that is, having two rows of teeth which cross each other producing tooth points across the surface in place of a continuous file tooth. Double-cut files have the first cut, called the "overcut," usually at an angle, say, of 45 degrees with the center line of the file. This is crossed with the upcut, at the opposite angle, at an angle of approximately 25 degrees. These angles will vary for different classes of files and for different uses. There is also what is known as rasp cut which differs from the single-cut and the double-cut in that the teeth are disconnected from each other, each tooth being made by a single pointed tool called a "punch."

File makers constantly try to improve the cutting quality of their product. The Disston Company now makes a file with staggered teeth and rounded gullets, to produce longer chips and avoid clogging. The Nicholson Company has also produced new file teeth for special work.

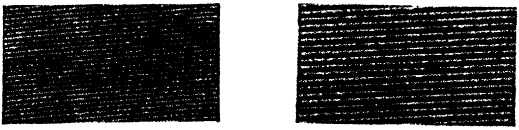

Rough Bastard


Second Cut Smooth

Dead Smooth

Actual Tooth Spacing of Double-Cut Files

Rough Second Cut


Smooth Smooth

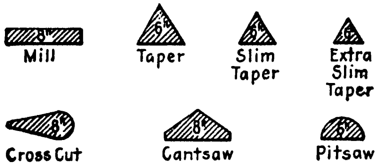
Actual Tooth Spacing of Single-Cut Files

For convenient classification and a better understanding, files may be grouped into three general classes:

The Saw-File Group

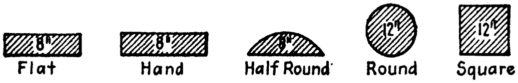
This group includes mill files; triangular saw files, such as tapers, slim tapers, extra-slim tapers, double-extra-slim tapers, double enders; crosscut, cantsaw, pitsaw, etc., all usually made single-cut.

Files in this group are made in various lengths, some extending from 4 to 16 inches, others from 3 to 12 inches, whereas some lines are confined to a very few sizes. Mill files are made in cuts of bastard, second-cut, and smooth. Some saw files are now made with teeth cut straight across to aid in filing teeth evenly.



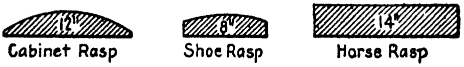
The Machinist's File Group

This second group includes flat, hand, half-round, round, square, warding, knife, etc., usually made double-cut with the exception of small rounds and the backs of the finer cuts of half-rounds, which are single-cut. Files in this group are made in bastard, second-cut, and smooth, and in lengths in some kinds and cuts extending from 4 to 20 inches, others in a small range of sizes.



Rasps and Miscellaneous Files

The third group includes flat and half-round wood rasps, cabinet rasps, show and horse rasps, cabinet files. These are made usually in a range of sizes from 6 to 14 inches, and sometimes 16 and 18 inches, or in some cases with a smaller variety of sizes.



In addition to the general classifications of files as indicated above, there are certain special shapes, kinds, and cuts of files made for certain specific special uses, the type and cut being determined by the particular service in which they are employed. These include aluminum files for automobile-body builders and workers on aluminum, sheet steel, etc.; brass files for use on various compositions of brass, bronze, etc.; testing files for testing the hardness of various tools and cutters; and curved-tooth files for use on soft materials and, to some extent, on wood and steel.

While regular files are generally made in a large assortment of sizes, files of the even-inch length are more often called for and are more largely sold than files of the odd-inch length.

Bastard-cut files are most commonly used, but second-cut and smooth-cut files are frequently required where finer finish to the work is needed.

There is also another very distinct group comprising so-called "Swiss pattern" files. This is made in a great variety of shapes and cuts and is a distinctive line, as compared with regular files, the shapes being made with smaller points and the cuts being numbered from #00, the coarsest, to #6, the finest. In this group there are hand, pillar, pillar-narrow, pillar-extra-narrow, three-square, warding, knife, half-round, crossing, barrette, round, square, crochet, round-straight, slitting, equaling, metal-saw, cant, die-sinker, round- and square-handle needle files, and filing-machine files. Sizes are usually from 3 to 10 inches, and the cuts most called for are #00, 0, 2, 4, and 6. Swiss pattern files are largely used for very particular work, like toolmaking, diesinking, jewelry work, and other fine work generally.

A clean file is much more effective than one that has been allowed to become filled with dirt or filings, and the use of a file card or brush for this service would be found advantageous. The use of chalk or oil is sometimes recommended, but the general rule should be to keep the file clean.

The height of the work or position in filing depends largely on the work to be filed and the conditions under which the filing must be done. For light, fine filing, work should be nearer on the level with the workman's eyes, but for heavy filing, work may better be nearer the floor. Generally, however, for filing in a vise, a range of from 40 to 44 inches from the floor to the work will be found best. For heavy filing, a height should be found that will give a position enabling the workman to get the full free swing of his arms from the shoulder.

Files are often worn out more by abuse than by use. They are intended to cut when in contact with the work and should be in such contact only during the advancing stroke, and pressure should be relieved during the back stroke, otherwise the sharp tooth points of the file will be damaged. Keep the file pressed firmly to the work. Keep it cutting. If not kept cutting with every stroke, the file wears out very quickly. The harder the material to be filed, the slower the stroke should be.

Files are also being made with teeth at a much sharper angle for some kinds of work. A single-cut file with teeth at 45 degrees, or more, is advocated where it is necessary to file lathe work. Irregularly spaced teeth are made to avoid clogging with soft metals, and the curved tooth files, sometimes known as the "Vixen," are widely used in some kinds of work. These are made seven and nine teeth to the inch.

In recutting files, some advocate the sand blast instead of annealing, grinding off old teeth, and recutting.

WHEN A FILE CUTS BEST

Edward G. Herbert, of Manchester, England, who gave the matter careful attention and has built file-testing machines, came to the conclusion that a file did not cut best when it is new, but after it has been used for some little time, say 2,500 strokes or the filing away of 1 cubic inch of metal. Another curious feature is that its usefulness seems to come to a sudden instead of a gradual end.

A bastard file having 25 teeth to the inch, operating on a surface 1 inch square with a pressure of 30 pounds, which is about equal to heavy hand filing, gives 25 cutting edges about 1 inch long, which likens it somewhat to a broad cutting tool in a planer.

In cutting a file the metal is forced up in a sort of burr and occasionally the top of the tooth slopes over backwards, which is the reason that a file often cuts better after these are broken or worn off. Then, too, when a file is new, all the teeth are not of the same height, and only a few points cut. As they wear down, more teeth come into contact and do more work.

ROTARY FILES

Rotary files are made for finishing dies and similar work. They are generally driven by a flexible shaft so that they can be moved in any direction to get at corners or other parts. They are made in a variety of sizes and with teeth of different fineness. The surface speeds usually recommended are from 80 feet per minute for use on hard or alloy tool steels to 250 feet for aluminum and similar alloys. Safe speeds for rotary files on various materials are given in the table herewith. Rotary files are made in many shapes to suit a wide variety of work.

Safe Speeds for High-Speed Steel Rotary Files
(In Revolutions per Minute)

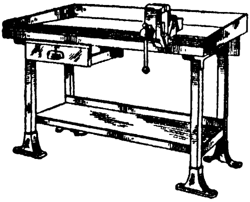
File Diameter, in Inches	Alloy Tool Steel	Carbon Tool Stee	Mild Steel	Cast Iron	Brass	Aluminum
$\frac{1}{16}$	5,000	6,420	7,500	4,800	12,000	16,000
$\frac{1}{8}$	2,500	3,200	3,750	2,400	6,000	8,000
$\frac{3}{16}$	1,670	2,150	2,500	1,600	4,000	5,400
$\frac{1}{4}$	1,250	1,600	1,875	1,200	3,000	4,000
$\frac{5}{16}$	1,000	1,300	1,500	960	2,400	3,200
$\frac{3}{8}$	835	1,100	1,250	800	2,000	2,700
$\frac{7}{16}$	720	920	1,075	690	1,900	2,300
$\frac{1}{2}$	625	800	1,000	600	1,500	2,000
$\frac{5}{8}$	500	650	750	480	1,200	1,600
$\frac{3}{4}$	420	550	625	400	1,000	1,400
$\frac{7}{8}$	360	475	550	350	950	1,200
1	320	450	500	250	750	1,000

Files are also made for filing machines. They may have special ends for machines of the jigsaw type or holes for fastening to belts in the machines of the band or continuous type.

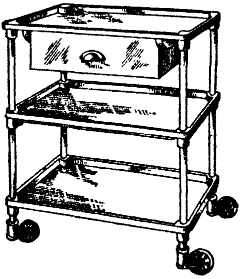
WORK BENCHES

Design and construction of work benches vary with the kind of work for which they are intended. Chipping and filing require a more rigid bench than assembling, unless the parts be heavy. The average shop must provide for various uses. Both wooden and metal tops are used, depending on both the kind of work and the preference of the user. Laminated maple is a favorite for wood, and combinations of wood in front and steel at the back are now common. The wood is usually about one-half of the total width. The laminated maple tops vary from 1¾ to 2¼ inches thick. Solid plank tops are also used as shown. The standard height of New Britain benches is 32 inches from top to the floor.

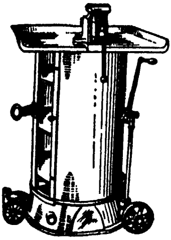
Cast-iron legs are almost obsolete, whether benches are built in the shop or are bought complete. Drawers are also of steel and back and end plates are common in some shops. Welded steel eliminates the annoyance of rivet heads.



Showing a Combination Steel and Wood Top



Three-tray Work-stand with Casters and Drawer



A Combined Work Bench and a Tool Cabinet; Stand Is Raised for Moving

Standard Solid Plank Construction

In addition to fixed benches, either against the wall or at right angles to the windows, there are now many uses for portable benches or stands. Some of these have casters while others have truck wheels under one end so as to be easily moved from place to place. Such stands may be used by repair men, and in some cases they are mounted on power-driven trucks to carry them from one part of the plant to another.

Battleship linoleum is frequently used for bench covering in instrument work. Others find ordinary corrugated paper, used with the corrugations up, advisable for assembling small mechanisms. The corrugations prevent small parts from rolling and the cover is cheaply and quickly renewed whenever necessary.

Portable vise stands for blacksmiths and other workers are now part of standard shop equipment, while tool stands and work stands are to be found in many shops. Some of these benches and stands are illustrated herewith. Steel benches are also made with firebrick tops for welding and brazing.

SECTION VII

BABBITTING, BRAZING, SOLDERING, AND WELDING

BABBITTING

Babbitting is the lining of a bearing with a soft metal to provide a suitable wearing surface for any rotating or sliding part. As the soft metal must be attached to the bearing itself by fusing, the operation bears a close relation to soldering.

Isaac Babbitt may be called the father of soft-metal bearings. His original mixture, in 1839, is supposed to have been 88.9 per cent of tin, 3.7 per cent of copper, 7.4 per cent of antimony. Many variations are now used to meet special requirements, such as armature shafts, rock crushers, and mill machinery. Lead, nickel, and phosphor bronze are used as alloys, and makers of babbitt metals should be consulted as to the best mixtures for special uses. The following suggestions are by the More-Jones Metal Company.

SUGGESTIONS FOR REBABBITTING BEARINGS

To ensure best results, the babbitt pot should be pyrometer controlled. If a pyrometer is not available, pour tin-base babbitt metals when, in the molten state, they will quickly ignite a dry white pine stick. Lead-base compositions are ready to pour when the molten metal browns, but does not ignite, a dry white pine stick.

The More-Jones Metal Company offers the following suggestions:

1. All old babbitt should be chipped or melted out of the bearing, and the inside of the shell scraped well with a wire brush or scraping tool. It is essential that the entire metal lining surface be perfectly clean and dry. If possible, boring is desirable. Then apply any good commercial soldering flux, and dip, brush, or spray the surface to be lined with molten half-and-half solder or pure tin. A small film of solder or tin will stick to the fluxed surface. More difficulty will be encountered in lining iron shells than those of bronze. Usually on large iron or bronze shells, anchor slots are employed, sometimes with and sometimes without the bonding process.

2. The bearing and mandrel should be quite warm—about 250°F.—but never excessively hot. A very hot mandrel will cause blistering and airpockets in the lining. The usual procedure is to chalk the mandrel or paint it with a mixture of clay and water, graphite, or similar refractory mixture, to prevent sticking. However, in some instances, better results are obtained by pouring against the

TABLE 1.—PHYSICAL PROPERTIES OF WHITE-METAL BEARING ALLOYS

Alloy No.	Formula				Deformation of Cylinder, 1¼ In. Diam. by 2½ in. High at 70°F., in Inches			Brinell Hardness		Melting Point		Complete Liquation Point		Specific Gravity	Weight		Proper Pouring Temperature, in Deg. Fahr.
	Copper, Per Cent	Tin, Per Cent	Antimony, Per Cent	Lead, Per Cent	At 1,000 Lb.	At 5,000 Lb.	At 10,000 Lb.	At 72°F.	At 212°F.	Deg. Fahr.	Deg. Cent.	Deg. Fahr.	Deg. Cent.		Oz. per Cu. In.	Grams per Cu. In.	
1	4.5	91.0	4.5		0.000	0.001	0.015	28.6	12.8	437.0	225	699.8	371	7.34	4.24	120.28	824
2	3.5	89.0	7.5		0.0000	0.0015	0.0120	28.3	12.7	460.4	238	683.6	362	7.39	4.27	121.10	808
3	8⅓	83⅓	8⅓		0.0010	0.0045	0.0070	34.4	15.7	462.2	239	791.6	422	7.46	4.31	122.25	916
4	3.0	75.0	12.0	10.0	0.0005	0.0025	0.0090	29.6	12.8	365.0	185	555.8	291	7.52	4.35	123.23	680
5	2.0	65.0	15.0	18.0	0.0010	0.0030	0.0090	29.6	11.8	365.0	185	536.0	280	7.74	4.48	127.00	661
6	1.5	20.0	15.0	63.5	0.0015	0.0050	0.0180	24.3	11.1	365.0	185	512.6	267	9.33	5.39	152.89	638
7		10.0	15.0	75.0	0.0010	0.0050	0.0230	24.1	11.7	464.0	240	500.0	260	9.73	5.62	159.44	625
8		5.0	15.0	80.0	0.0020	0.0090	0.0620	20.9	10.3	469.4	243	500.0	260	10.04	5.80	164.52	625
9		5.0	10.0	85.0	0.0040	0.0120	0.0840	19.5	8.6	469.4	243	491.0	255	10.24	5.92	167.80	616
10		2.0	15.0	83.0	0.0010	0.0100	0.1540	17.0	8.9	473.2	245	500.0	260	10.07	5.82	165.02	625
11			15.0	85.0	0.0010	0.0100	0.1910	17.0	9.9	476.8	247	500.0	260	10.28	5.94	168.46	625
12			10.0	90.0	0.0025	0.0170	0.2850	14.3	6.4	476.8	247	509.0	265	10.67	6.17	174.85	634

bare mandrel. Jig and assembly should be checked for leaks and made as tight as possible to prevent the loss of metal during the pouring.

3. It is advisable to melt the babbitt as close to the place of pouring as possible. If molten metal is carried any great distance, it has a tendency to cool rapidly, and by the time it is poured, it may be approaching a sluggish state. Under these circumstances, it is advisable to heat the babbitt from 25 to 50 degrees over the figures shown in Table 1 to allow for rapid cooling between pot and job. Good tight linings cannot be obtained when the metal is not fluid.

4. Melting of babbitt should take place slowly. The babbitt must be at the proper temperature for pouring. As soon as babbitt begins to melt, the surface should be covered with powdered charcoal. This will retard formation of oxides and accumulation of dross, and act as a protective covering from the air. When bars or ingots have been completely melted and the babbitt is in a fluid state, stir thoroughly, *over and over* in the pot—*not around and around*. If possible, the same person or persons should do the rebabbitting, for experience leads to the best results.

5. A ladle or ladles sufficiently large to hold all the metal necessary to pour entire bearing at one time should be on hand, and more babbitt melted than actually required. If another pour has to be made, after part of the lining has set, a definite seam is formed. This weakens the bond and causes premature loose linings, squashing, rapid wear, and sometimes complete failure.

6. The metal should be thoroughly skimmed, then ladled out, dipping from below the surface, and poured slowly and steadily in a thin stream. A thick stream, which quickly fills the lining aperture, prevents escape of air, and causes blow-holes or seams. The lining will shrink somewhat when poured, so more babbitt should be steadily added, during the setting process, until the lining is at least flush with the end of the bearing.

NOTE.—Be sure bearing and mandrel are not wet or damp, for hot metal coming into contact with moisture will splash or explode, sometimes causing painful and serious burns to the workmen.

Some experimenting may be necessary to secure the most efficient results with your particular bearings and shop facilities. However, good babbitts, if properly applied, will ensure long and satisfactory bearing life. A little practice—keeping in mind the foregoing suggestions—should give thoroughly satisfactory linings.

SOLDERING

A point frequently overlooked in soldering is the importance of properly cleaning the surfaces to be joined. This is too often left for the flux to correct. Another neglected point is the selection of the best flux to be used. The after effects resulting from improper cleaning after soldering are frequently worse than the good effect of the soldering. This is particularly noticeable in electrical work.

For strength, fit the parts accurately. The more accurate the fitting, the stronger the result. Use a solder with as high a melting point as possible. Apply the proper heat. The nearer the temperature of work to be joined is brought to the fusing point of the solder the better will be the union, since the solder will flow more readily.

Fluxes for Different Metals

There are on the market a number of fluxes or soldering salts that are giving good satisfaction. A form that is noncorrosive and very popular with electrical workers is the soldering stick in which the ingredients are molded into stick form.

TABLE 2.—MATERIALS USED FOR TYPICAL SOLDERING JOBS

Job	Solder	Flux	Neutralizer
General electrical connections in assemblies which cannot be washed	45 % tin—55 % lead or 33 % tin—67 % lead	Rosin	None
Running seams on sheet metal (other than lead and its alloys)	45 % tin—55 % lead or 33 % tin—67 % lead	Soldering salts (Ammonium chloride and zinc chloride) Naphthalene Tetrachloride	Cyanide wash, hot-water wipe, or alcohol wash
Copper, brass, phosphor bronze, nickel, silver, tinned and untinned sheet	45 % tin—55 % lead or 33 % tin—67 % lead	Soldering salts (Ammonium chloride and zinc chloride) Naphthalene Tetrachloride	Cyanide wash, hot-water wipe, or alcohol wash
Galvanized iron sheet	45 % tin—55 % lead or 33 % tin—67 % lead	Soldering salts (Ammonium chloride and zinc chloride) Naphthalene Tetrachloride	Cyanide wash, hot-water wipe, or alcohol wash
Wiping and soldering lead joints	40 % tin—60 % lead	Stearic acid	Burning
Tinned parts that can be washed after soldering	45 % tin—55 % lead or 33 % tin—67 % lead	Naphthalene Tetrachloride	Alcohol wash
Splicing copper wire where low electrical resistance and high strength are essential	20 % silver—45 % copper—35 % zinc*	Borax	None
Repairing brass castings where high strength is essential	45 % silver—30 % copper—25 % zinc*	Borax	None

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* These are not what are generally termed soft solders, a torch being required.

A flux in soldering removes and prevents the formation of an oxide during the operation of soldering, and allows the solder to flow readily and to unite more firmly with the surfaces to be joined.

The suggestions in Table 2 are by A. H. Folk of the Bell Telephone Laboratory.

Cleaning and Holding Work

For copper work a dilute sulphuric acid is best. Articles of lead and zinc can be cleaned with a potash solution, but care must be exercised as the alkalies attack these metals. For zinc, a dilute solution of sulphuric or muriatic acid will clean the surface.

For cleaning or removing the oxide or other foreign material, scrapers and files are frequently used. An old file bent at the ends and with the corners flaring makes a handy tool. Grind the edge sharp, and make as hard as possible.

To enable difficult points to be "filled," sometimes a small piece of moist clay pressed into shape to form the desired shape can be used to advantage as a guide for the solder. Another use of the clay is to embed the parts in, to hold them in position for soldering.

Plaster of paris is also used for this purpose, but it is sometimes difficult to remove, especially in hollow pieces. A dilute solution of muriatic acid will help to get this out, however.

Castings containing aluminum are always harder to solder than other alloys. In some instances where the percentage of aluminum is high, it is necessary to copperplate the parts to be joined before a satisfactory joint can be made. In nearly every instance the work can be "stuck" together, but not actually soldered.

In metal-pattern making too little attention is given to both the fitting of the parts and the selection of the solder to joint the work. A good grade should always be used, and it must be borne in mind that the higher the melting point of the solder the stronger the joint.

A very good job of soldering can be done on work that will permit of it by carefully fitting the parts, laying a piece of tin foil, covered on both sides with a flux, between the parts to be joined and pressing them tightly together. Heat until the foil is melted. This is very good in joining broken parts of brass and bronze work. If they fit well together, they can frequently be joined in this manner so that the joint is very strong and almost imperceptible.

Soldering Cast Iron

For cast iron, the flux is usually regarded as a secret. A number of methods are in use. One of the oldest and least satisfactory is to brush the surfaces thoroughly with a brass scratch brush. Brush until the surface is coated with brass, then tin this surface and solder as usual. If plating facilities are to be had, copperplate the parts and solder together. This method has been used very successfully for a number of years.

A fair substitute for the above is to clean the surfaces thoroughly and copperplate them with a solution of sulphate of copper: about 1 ounce sulphate of copper, ½ pint water, ⅓ ounce sulphuric acid.

Brush this solution on or dip into the solution, rinse off and dry it well before soldering.

Another method is to tin the cast iron. To do this, first remove all scale until the surface is clean and bright. The easiest way to do this is with the emery wheel. Dip in a lye to remove any grease, and rinse the lye off; then dip into muriatic acid of the usual strength. Then go over the surface with rosin and a half-and-half solder. It may be necessary to dip into the acid several times to get the piece thoroughly tinned. Rubbing the surface of the iron with a piece of zinc while the acid is still on it will facilitate the tinning.

Another method of soldering cast iron is to clean the surface as in the previous operation, and then brush over with chloride of zinc solution and sprinkle powdered sal ammoniac on it; then heat until the sal ammoniac smokes. Dip into melted tin and remove the surplus; repeat if not thoroughly tinned. Half tin and half lead works well as a solder for this.

Commutator wires and electrical connections should never be soldered by using an acid solution, owing to the corrosive action afterward. A good flux is an alcoholic solution of rosin.

Solders and Fusible Alloys

Solders act under constant stress considerably like plastic or semi-fluid material. Their fluidity resembles that of tar or gum, and their distortion with time is greater than would be thought. In a series of tests, a notable point brought out was the varying degrees of strength with age. Tensile strength increases with the percentage of tin present, but when the solder's age is increased as a factor, the product possesses its maximum value at 60 per cent tin, showing this property as similar to that of the melting point and depending upon chemical composition.

For general work, the solder requiring resistance to stress is 60 per cent tin, but for work requiring little mechanical strength, such as sealing, a lower per cent of tin may be used.

Generally speaking, all solders are alloys of lead and tin. The more lead the alloy contains above 40 per cent, the **higher** is its melting point; and also the less lead it contains below 40 per cent, the **lower** is its melting point.

Nearly all aluminum solders are alloys of tin and aluminum that contain from 15 to 25 per cent aluminum. A small per cent of copper or nickel, never exceeding 2 or 3 per cent, is sometimes used. The exact point of separation between a fusible metal and a non-fusible one is very uncertain; thus, several additional alloys are given in the table. In filling up imperfections in ornamental castings for plugs in electrical wiring, and on boilers in engineering work, fusible alloys are used. Sometimes defects in structural steel have been filled in with expanding alloy and then covered with a coat of paint. The United States Government rules call for pure Banca tin for boiler plugs, but this is not essential, and any good tin will serve the purpose.

Experiments show that any pressure upon the solder at the moment of setting diminishes the strength of the joint. Thus, in making a solder joint, the upper piece should be held above the lower one, the solder fused by means of two blowtorches, and the pieces brought together by very slow and easy pressure. By employing this method, which differs from that commonly called "sweating," the joint is less liable to be broken, because the crystalline composition of the resulting mass contains less resistance at this time.

In addition, it is found that there is remarkable variation with time of the tensile strength of such joints, which is also in accord with what would be considered proper by engineering science in this field. Under any circumstances, the average strength attained does not exceed 27,000 pounds per square inch and was obtained from solder made with three-fifths of its composition tin.

The melting point of alloys which fuse at a low temperature may be found by tying a small wire around a fragment of alloy and hanging it in a bath of water. A thermometer should be kept in the bath and the temperature increased slowly until the alloy melts. The melting point of the alloy can then be noted by the temperature of the bath. For higher temperature a bath of paraffin or oil is used. If bismuth is added to these alloys, the melting point is lower, as bismuth possesses the quality of expanding on cooling, a property which is very unusual in metals. Bismuth is used not only to make the alloy or solder more easily worked by diminishing its melting point, but, if sufficient quantity be present, its expansive tendency

TABLE 3.—MELTING POINTS OF SOLDER METAL
AMERICAN SOCIETY FOR TESTING MATERIALS

Grade	Formula, Per Cent			Melting Point	
	Tin	Lead	Antimony	Degrees Centigrade	Degrees Fahrenheit
Tin	100.00			232	449.6
0 A	63.00	37.00	0.12	181	357.8
1 A	50.00	50.00	0.12	181	357.8
1 B	49.25	50.00	0.75	185	365.0
2 A	45.00	55.00	0.12	181	357.8
2 B	43.50	55.00	1.50	188	370.4
3 A	40.00	50.00	0.12	181	357.8
3 B	38.00	60.00	2.00	188	370.4
4 A	37.50	62.50	0.12	181	357.8
4 B	35.50	62.50	2.00	188	370.4
5 A	33.00	67.00	0.12	181	357.8
5 B	31.00	67.00	2.00	188	370.4
Lead		100.00		327	620.6

Class A solders are made from new metal only. Class B from at least one-half new metal. For galvanized iron and zinc only Class A should be used. Grade 4 is suitable for wipe joints.

counterbalances the effects of the contraction of the other metals, and the total result is the prevention or reduction of shrinkage in the mold. The addition of cadmium still further lowers the melting point of such alloys as those of bismuth, lead, and tin, which in themselves have very low melting points.

It is recommended that the grade of solder metal be selected which contains the least amount of tin required to give suitable flowing and adhesive qualities for the work in hand.

TABLE 4.—COMPOSITION AND MELTING POINT OF FUSIBLE ALLOYS

Alloy	Lead	Tin	Bismuth	Other Constituents	Melting Point	
					Cent.	Fahr.
1. Steam-boiler plug	48.4	38.8	12.8		171	340
2. Steam-boiler plug	44.5	33.3	22.2		141	285
3. Steam-boiler plug	42.1	15.8	42.1		123	253
4. Steam-boiler plug	10.0	40.0	50.0		116	240
Sir Isaac Newton's	30.0	20.0	50.0		100	212
Suitable for casts	31.25	18.75	50.0		98	208
Rose's alloy	28.1	21.9	50.0		95	203
D'Arcet's alloy	25.0	25.0	50.0	Cadmium	93	200
Wood's alloy	25.0	12.5	50.0	12.5	60	140
Lipowitz's alloy	26.9	12.7	50.0	10.4	66	150
Expanding alloy	66.7		8.3	25.0	66	150

BRAZING AND HARD SOLDERING

The main difference between soldering and brazing is in the kind of metal used in making the joint and in the temperature required to melt it. Brazing is done with a torch, in a fire, or by dipping the joint to be brazed into the molten metal used for making the joint. This is called "dip" brazing.

Hard solders contain more or less copper and are frequently referred to as "spelter." A substantial solder contains 60 per cent copper, 20 per cent tin, and 20 per cent zinc. An easily melted yellow, hard solder contains about 45 per cent copper and 55 per cent zinc. This solder is really a brass, but at times it is used for soldering, binding, and filling purposes.

Tests made by F. Grotts, chief metallurgist of the Curtis Aeroplane & Motor Co., in 1918, gave valuable information on brazing. A copper-zinc alloy (4 parts copper to 1 part zinc) gave a strength of 31,200 to 39,800 pounds per square inch. An alloy of 83 per cent copper, 17 per cent zinc gave joints somewhat stronger. With a flux of boric acid, brazing is easy and satisfactory.

Joints brazed with copper-zinc alloys and boric acid in a gas fire nearly all exceeded the maximum strength of the cold-drawn steel used in the tests.

The oxyacetylene torch, however, gave a stronger joint than dip brazing or the gas fire, the strength being in the order named.

Heat-treating by heating to 1600°F., quenching in oil, and reheating to 900 degrees increased the strength of the brazed joint an average of 23 per cent.

Untreated brazed joints were 19.2 per cent stronger than untreated welded joints. Treated brazed joints were 55 per cent stronger than untreated welded joints. The treated welded joint was 42 per cent stronger than the untreated joint.

Brazing Band Saws

The use of band saws in cutting out dies and other internal work has led to the development of small electric heating devices that are attached to the machine. The saw joint is reopened by melting the silver solder used in the joint. The end of the saw is threaded through a drilled hole and the ends brazed in the small welder. After a joint has been brazed 5 or 6 times, it is best to make a new joint at a fresh point in the saw. A small grinding fixture is provided to grind the lap joint at the proper angle. Silver solder and flux are applied to the joint, and the heat is turned on. The joint is stronger than the saw itself. The time for an internal sawing set-up is less than 5 minutes.

Silver Brazing[1]

Silver brazing is often economical because joints require but little finishing. It is used in aircraft work for safety of joint. Silver solder is made in sheet, strip, wire, or granule form to melt from 1250 to 1600°F. The average flow is at slightly over 1400°F. Silver solder has 40 to 50 per cent silver and copper and zinc. Increasing zinc to equal copper lowers the melting point.

A silver-copper mixture of 72 per cent silver and 28 per cent copper melts at 1435°F. Tin lowers the melting point but tends toward brittleness. Nickel hardens the solder and raises the flow point. Even small quantities of lead and iron cause difficulties.

Borax makes a good flux. Commercial borax should be calcined (fused) to drive out water. A saturated solution of sodium cyanide, or potassium cyanide, with a little borax or boric acid is convenient for small work but lacks the fluxing qualities of borax.

Make a saturated solution of borax by dissolving in hot water, and apply hot to get an even coating. Or mix powdered borax with clean water to a creamy paste, or mix fused borax with alcohol.

Care must be used in heating to attain and maintain right temperature. Use a blowpipe for small work. If an oxyacetylene flame is used, it must be kept moving.

Dipping in cold water after brazing will disintegrate the flux. A little sulphuric acid helps to remove the film.

WELDING

Oxyacetylene Cutting and Welding

Cutting and welding metal with oxyacetylene have become common practice in both large and small shops. A blowpipe provided

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[1] A. Eyles

with the proper tip mixes oxygen and acetylene in the right proportions to produce a neutral flame, that is, a flame with no excess of either gas. It is the hottest flame known. Applied to the edges of two pieces of metal the concentrated heat melts or fuses the metals together. This is called "autogenous welding."

One great advantage of this process is that all commercial metals can be welded. When the joint is to be made in a metal more than $\frac{3}{16}$ inch thick, the edges should be beveled so that the welding can begin at the bottom and build up. The bevel is usually about 90-degrees included angle and is filled gradually with metal from the sides as well as from the welding rod used.

The heat generated by the welding naturally causes expansion that must be considered and provided for, otherwise the contraction due to cooling may cause trouble. Castings are frequently preheated with charcoal, both because it is cheap and because it heats slowly. In some cases, such as locomotive frames, gas torches are sometimes used for preheating. The effect of the welding flame on the work can be varied by moving it to or from the work and also playing it around on the metal.

The welding rod used should be carefully selected for the work. In welding some metals, the proper rod will supply the alloys burnt out by the intense heat of the welding flame. Attention should also be paid to securing the proper flux for the metal being welded. Generally speaking, there are three kinds of fluxes; for cast iron, for aluminum, and for brasses and bronzes. The flux is used to float the oxides out of the weld. Some welders of aluminum do this with a steel rod flattened at one end to stir or puddle the oxide and scrape it off the surface of the weld.

In some work where extreme heat is not required, either city or natural gas is used with oxygen, instead of acetylene. This combination is useful in lead storage battery work, soft soldering, silver soldering, and light brazing. The use of city or natural gas requires a larger tip than where acetylene is used.

Welding and cutting can both be done mechanically in machines having either hand or automatic feed. In such work a lower pressure is generally used.

Blowpipe tips should be cleaned with a soft brass or copper wire.

There should be a fire-resisting wall between stored tanks of oxygen and oxyacetylene, whether the cylinders be full or empty.

Close valves on all cylinders except when they are in use, even if they are empty.

If flame backfires first shut off the blowpipe oxygen valve, then the acetylene valve.

It is now standard practice to use a *red* hose for acetylene and a *green* hose for oxygen.

FLAME CUTTING

Flame or gas cutting is done with what is known as an oxygen "lance," which can also be used to pierce a piece of considerable thickness. After a small spot of metal has been heated red hot by a combined flame of oxygen and acetylene, the acetylene is turned off, and only a jet of oxygen used. The hot iron and oxygen combine to form iron oxide by an extremely rapid rusting process, the oxygen jet blowing the rust away as fast as it is formed. According to R. F. Helmkamp, of the Air Reduction Sales Company, practically all classes of wrought iron, rolled steel, and steel castings may be flame cut. Steels under 0.30 per cent carbon can be cut without heat-treatment either before or after cutting. Alloy steels should be preheated and annealed after cutting. For piercing the end of a heavy connecting rod the forging is preheated to about 1000°F.

In cutting high-carbon or alloy steels it is customary to leave about ¼ inch of metal for finishing as this permits the removal of any metal that might have been injured by the intense local heat. Data on speed and cost of flame cutting are given in the accompanying table.

TABLE 5.—APPROXIMATE GUIDE FOR MACHINE CUTTING

Thickness, in inches	¼	⅜	½	¾	1	1½	2	3	4	5	6	8	10	12
Airco, DB tip, style 124	0	1	1	2	2	3	4	5	5	6	6	7	7	8
Pressure, in pound per square inch:														
Oxygen	30	30	40	40	50	50	50	50	50	50	55	60	70	70
Acetylene	3	3	3	3	3	3	3	4	4	5	5	6	6	6
Speed, in inches per minute	20	19	17	15	14	12	10	8	7	6	5	4	3½	3
Consumption, in cubic feet per hour:														
Oxygen	50	75	90	120	140	200	255	335	385	460	495	650	735	875
Acetylene	9	12	12	14	14	16	17	22	22	28	28	35	35	40
Approximate width of Kerf, in inches	5/64	3/32	3/32	7/64	7/64	⅛	9/64	11/64	11/64	3/16	3/16	7/32	7/32	¼

TABLE 6.—FLAME CUTTING WITH AIRCO MACHINES

Thickness of Steel, in Inches	Cutting Tip		Gas Pressure, Pounds per Square Inch		Flame Kerf Width, in Inches	Cutting Speed	
	Size Number	Style Number	Oxygen	Acetylene		Inches per Minute	Feet per Hour
¼	0	23	35	4½	3/64	22 to 27	110 to 125
5/16	1	23	40	4	1/16	21 to 28	105 to 130
½	1	23	55	4½	⅛	20 to 24	100 to 120
¾	2	24	50	2	⅛	18 to 22	90 to 110
1	2	24	55	2½	5/32	14 to 18	70 to 90
1½	3	24	55	3	5/32	12 to 15	60 to 75
2	3	24	60	3½	3/16	9.5 to 12	47.5 to 60
3	4	25	50	3½	3/16	8 to 10	40 to 50
4	4	25	60	4	3/16	6.5 to 8.5	32.5 to 42.5
5	4	25	65	4½	3/16	5.5 to 7	27.5 to 35
6	5	25	65	4½	7/32	4.5 to 5.5	22.5 to 27.5

Machine cutting table for ¼- to 6-inch thickness of good mild steel, clean surface, not preheated, Airco D-B Oxygraph, Camograph, and Radiagraph.

TABLE 7.—OXWELD HAND CUTTING BLOWPIPE

Thickness, in Inches	Nozzle, Type and Size		Oxygen Pressure, in Pounds per Square Inch	Linear Cutting Speed Range, in Inches per Minute	General Consumption Range			
	C-2 C-6 C-11 C-14 *CW-17	C-24 C-31 C-32 †CW-22 †CW-23			Oxygen, in Cubic Feet per Hour	Acetylene, in Cubic Feet per Hour	Oxygen, in Cubic Feet per Minute	Acetylene, in Cubic Feet per Minute
1/16		No. 2	7 to 25					
1/8	No. 0	No. 4	15 15 to 23	19.9 to 29.8	45 to 55	7.2 to 8.8	0.8 to 0.9	0.12 to 0.15
1/4	No. 1	No. 6	20 11 to 17	17.6 to 25.8	77 to 93	8.7 to 10.7	1.3 to 1.6	0.15 to 0.18
3/8	No. 2	No. 6	25 17 to 24	16.0 to 23.7	95 to 115	9.7 to 11.9	1.6 to 1.9	0.16 to 0.20
1/2	No. 2	No. 6	30 20 to 28	14.8 to 22.2	105 to 125	10.5 to 12.9	1.8 to 2.1	0.18 to 0.22
3/4	No. 2	No. 6	35 24 to 34	13.1 to 19.8	117 to 143	12.0 to 14.6	2.0 to 2.4	0.20 to 0.24
1	No. 2	No. 6	40 28 to 40	11.8 to 18.0	130 to 160	13.0 to 16.0	2.2 to 2.7	0.22 to 0.27
2	No. 3	No. 8	45 22 to 30	8.6 to 13.0	185 to 225	16.2 to 19.8	3.1 to 3.8	0.27 to 0.33
3	No. 3	No. 8	55 33 to 43	6.6 to 9.8	240 to 290	18.5 to 22.7	4.0 to 4.8	0.31 to 0.38
4	No. 3	No. 8	65 42 to 55	5.2 to 7.8	293 to 357	21.1 to 25.9	4.9 to 6.0	0.35 to 0.43
5	No. 3	No. 8	75 53 to 67	4.2 to 6.4	347 to 423	23.9 to 29.3	5.8 to 7.1	0.40 to 0.49
6	No. 4	No. 10	75 45 to 58	3.5 to 5.4	400 to 490	26.5 to 32.3	6.7 to 8.2	0.44 to 0.54
8	No. 4	No. 10	95 60 to 77	2.6 to 4.2	505 to 615	31.5 to 38.5	8.4 to 10.3	0.53 to 0.64
10	No. 4	No. 10	115 75 to 96	1.9 to 3.2	610 to 750	36.9 to 45.1	10.2 to 12.5	0.62 to 0.75
12	No. 4	No. 12	140 69 to 86	1.4 to 2.6	720 to 880	42.3 to 51.7	12.0 to 14.7	0.71 to 0.86

These tables are approximate.

Lowest speeds and highest gas consumption are for inexperienced operators, short cuts, dirty or poor metal. Highest speeds and lowest gas consumption are for thoroughly experienced operators, long cuts, good clean metal.

* This cutting attachment is intended for cutting up to 2 in.

† This cutting attachment will cut up to 8 in.

Fusion Welding

This is a term applied to any welding process where metals are joined without hammering, as with forge welding. It includes both gas and electric welding, with or without the use of filler metal, such as arc, resistance, shot, and spot welds with electricity and oxyacetylene or other gas welds. In shot welding, current is applied intermittently, making spot welds as frequently as desired.

TABLE 8.—OXWELD HAND WELDING BLOWPIPE CHART

Thickness		Size of Tip	Specific Range			General Range		
			Oxygen Pressure Range, in Pounds, per Square Inch	Consumption		Consumption		Speed
Inches	Gage			Oxygen, in Cubic Feet per Hour	Acetylene, in Cubic Feet per Hour	Oxygen, in Cubic Feet per Hour	Acetylene, in Cubic Feet per Hour	Linear Feet per Hour
	28	No. 1	9	1.5	1.4	1.0 to 2.0	0.93 to 1 87	30 to 40
		No. 1	16 to 24	1.8 to 2.2	1.7 to 2.0			
	25	No. 2	16 to 24	3.1 to 4.0	2.9 to 3.7	2.5 to 4.5	2.34 to 4.20	27 to 36
1/32	22	No. 2	10	4.5	4.2	3.5 to 5.5	3.3 to 5.1	25 to 32
		No. 2	16 to 24	3.1 to 4.0	2.9 to 3.7			
		No. 3	16 to 24	4.0 to 5.2	3.7 to 4.9			
1/16	16	No. 3	10	6.6	6.2	5.0 to 8.5	4.7 to 7.9	19 to 29
		No. 3	16 to 24	4.0 to 5.2	3.7 to 4.9			
		No. 4	16 to 24	5.8 to 7.3	5.4 to 6.8			
3/32	13	No. 4	11	8.7	8.3	7.0 to 11.0	6.5 to 10.0	16 to 23
		No. 4	16 to 24	5.8 to 7.3	5.4 to 6.8			
		No. 5	16 to 24	9.2 to 11.7	8.6 to 10.9			
		No. 6	10 to 12	11.0 to 12.5	10.3 to 11.7			
1/8	11	No. 5	12	10 8	10.2	9.0 to 14.0	8.4 to 13.1	12 to 20
		No. 5	16 to 24	9.2 to 11.7	8 6 to 10.9			
		No. 6	16 to 24	11.5 to 14.2	10.7 to 13.3			
		No. 7	16 to 24	13.7 to 17 0	12.8 to 15.9			
		No. 6	10 to 12	11.0 to 12.5	10.3 to 11.7			
3/16	..	No. 6	14	15.0	14.2	13.0 to 18.0	12.1 to 16.8	7 to 12½
		No. 6	16 to 24	11.5 to 14.2	10.7 to 13.3			
		No. 7	16 to 24	13.7 to 17.0	12.8 to 15.9			
		No. 7	13 to 15	16.0 to 17.5	15 0 to 16.3			
1/4	..	No. 7	16	19.2	18.3	17.5 to 25.0	16.3 to 23.4	5 to 9
		No. 7	13 to 15	16.0 to 17.5	15.0 to 16.3			
		No. 8	13 to 15	21.0 to 22.5	19.6 to 21.0			
3/8	..	No. 8	19	25.0	23.8	25.0 to 34.0	23.4 to 31.8	3 to 6
		No. 9	20	30.5	29.0			
		No. 9	14 to 16	31.5 to 34.0	29.4 to 31.8			
1/2	..	No. 10	21	36.0	34.3	36.0 to 46.0	33.6 to 43.0	2½ to 4½
		No. 10	16 to 18	41.5 to 44.0	38.8 to 41.0			
5/8	..	No. 11	23	44.0	41.8	43.0 to 56.0	40.0 to 52.0	2 to 3
		No. 10	16 to 18	41.5 to 44.0	38.8 to 41.0			
		No. 11	17 to 19	50.5 to 53.5	47.2 to 50.0			
3/4	..	*No. 12	25	52.8	50.4	53.0 to 67.0	49.5 to 62.5	1½ to 2½
		No. 12	19 to 21	65.0 to 69.0	60.7 to 64.5			
1	..	*No. 15	30	69.7	66.3	74.0 to 95.0	69.0 to 88.0	1 to 2
		No. 13	27 to 29	80.5 to 84.5	75.0 to 79.0			
Heating		No. 20	35	105.0	100			
		No. 30	45	158.0	150			
1½	..	No. 100	50 to 60	105	100			
2	..	No. 125	50 to 60	132	125			
3	..	No. 150	50 to 60	158	150			
Heating		No. 175	55 to 65	184	175			
		No. 250	60 to 70	264	250			

The general range represents approximately the lowest and highest speeds and gas consumption for each thickness of metal, regardless of the size and type of tip used. Best results are based on long welds by experienced operators, and the lowest on short welds by inexperienced operators.

The specific range represents approximately the maximum and minimum capacity of various welding tips that can be used to weld a particular thickness of metal.

The consumption of these tips is slightly below the "general range."

FLUXES FOR OXYACETYLENE WELDING AND BRAZING

General Flux Characteristics

Phase.—Best applied to welding rod as a paste (suspension of powdered salts in water or alcohol). Sometimes applied as a dry powder or injected as a vapor into the welding atmosphere.

Melting Point.—Below temperature where an appreciable amount of oxide forms on base metal.

Film.—Uniform, quiescent, transparent.

Density.—Light and easily floated; no tendency to be trapped in weld metal.

Viscosity at Welding Temperatures.—Should be sufficient to keep the weld metal covered and protected from gas absorption and oxidation, but not so viscous as to prevent ready fusion of the welding rod and weld metal.

Oxide Solvent.—Should readily dissolve base metal oxides as well as weld metal oxides and keep contact surfaces clean at welding temperatures. (Base metal should almost always be cleaned before welding.)

Weld Appearance.—All the above characteristics should combine to permit the rapid deposition of a weld free from oxides, flux inclusions, or gas pockets with smooth, clean surfaces free from overlaps or pits.

Specific Flux Characteristics

ALUMINUM ROD

Type A.—An aluminum welding flux composed generally of alkall halides; characterized chiefly by the speed with which solid welds in sheet metal may be made with smooth fusion at the root of the weld and without pitting or discoloration on the surface.

Type B.—A modified aluminum welding flux with additions of higher melting point constituents like borates and other chemicals to provide greater slagging action as well as additional viscosity, resistance to oxidation, and protection while making repairs in cast aluminum parts by puddle welding.

BRONZE ROD

Type C.—An "oxidizing" flux ordinarily made with a boric acid base. It should form a thin but strong oxide film on the surface of the molten copper alloy, thereby preventing gas absorption and excessive oxidation. Recommended for clean or cleaned iron and steel surfaces.

Type D.—Where oxidized, rusty, or dirty surfaces are to be joined, an "oxide solvent" flux ordinarily made with a borax base

TABLE 9.—OXYACETYLENE WELDING PROCEDURES

Base Metal	Fusion Welding			Brazing		
	Filler Metal	Flame[1]	Flux	Filler Metal	Flame[1]	Flux
Lead	Same as base metal	N	None			
Aluminum (soft)	Same as base metal	SR to N	Type A	Aluminum solder	N or R	None
Aluminum alloy (wrt.)	Same as base metal	SR to N	Type A	Aluminum solder	N or R	None
	Silicon-aluminum alloy	SR to N	Type A			
Cast aluminum	Silicon-aluminum alloy	SR to N	Type B			
Yellow brass	Similar to base metal	O	Type C	Silver alloy or phos-copper	SR to N	Type H
Red or leaded brass	High zinc brass[2]	N	Type C	Silver alloy or phos-copper	SR to N	Type H
Silicon bronze	Similar to base metal	N to SO	Type C	High zinc brass[2]	N to SO	Type C
				Silver alloy or phos-copper	SR to N	Type H
Copper	Deoxidized copper	N	None	High zinc brass[2]	N to SO	Type C
				Silver alloy or phos-copper	SR to N	Type H
Nickel	Same as base metal	R	None	Silver alloy	SR to N	Type H
Nickel-copper alloy	Same as base metal	N to SR	Type C	Silver alloy	SR to N	Type H
	Silicon-monel	N to SR	None			
Cast iron	Similar to base metal	N	Type F	High zinc brass[2]	N to SO	Type E
Malleable iron	White cast iron[3]	N to R	Type F	High zinc brass[2]	N to SO	Type C
Galvanized iron	....	......	......	High zinc brass[2]	N to SO	Type C
Carbon steel	Low carbon steel	N	None	High zinc brass[2]	N to SO	Type C or I
	Low alloy steel	SR	None	Silver alloy	SR to N	Type H
Alloy steel	Similar to base metal	SR	None	Silver alloy	SR to N	Type H
Stainless iron & steel	Similar to base metal[4]	N	Type G	Silver alloy	SR to N	Type H
High manganese steel	Similar to base metal	N to SR	None			

Houston E. Landis, Jr., and F. C. Saacke, Air Reduction Sales Co.

[1] N—Neutral.
O—Oxidizing.
R—Reducing.
SR—Slightly reducing.
SO—Slightly oxidizing.

[2] High zinc (38 to 44 %) brass with additions of alloying elements such as tin, iron, manganese, silicon, nickel.

[3] Fusion welding of malleable iron should be followed by remalleableizing heat treatment.

[4] 18-8 stainless steels often alloyed and "stabilized" with columbium, titanium, molybdenum, tungsten.

and having a high solvent action for metallic oxides is recommended. It should keep both the base metal and the molten puddle clean and bright.

NOTE:,This flux will not give as good weld metal characteristics as the Type C flux applied to clean surfaces.

Type E.—A "highly oxidizing" brazing flux designed specifically for removing carbon or graphite from the surfaces of cast iron. Usually contains an oxidizing component such as manganese dioxide.

NOTE: This flux often used with the Type C flux to provide the proper tinning action.

CAST IRON ROD

Type F.—Ordinarily made with a borax base and containing alkali salts to aid in fluxing the slag that forms on cast iron. Should permit ready fusion of the welding rod and base metal without leaving gas pockets or inclusions.

STAINLESS STEEL ROD

Type G.—A stainless steel welding flux designed to permit complete fusion at the root of a weld without burning. The best test for a flux of this type is to coat the root of a butt joint with the paste and then observe the penetration at the root after making the weld.

SILVER BRAZING ALLOY

Type H.—A silver "soldering" flux made from an alkali bifluoride and borax or boric acid; gives the best results on both nonferrous and ferrous alloys, including stainless.

Cutting with the Arc

Cutting metals with the electric arc is merely applying heat of the arc along the desired line. Cuts with an arc are not so smooth as with the gas torch, but the arc is cheaper and is not restricted to ordinary ferrous metals. Direct current with a carbon electrode negative is usual, but alternating current can be used. C. H. Jennings, research engineer of Westinghouse, gives the following tables:

TABLE 10.—CURRENT VALUES FOR VARIOUS SIZES OF GRAPHITE ELECTRODES

ELECTRODE DIAMETER, IN INCHES	CURRENT VALUES, IN AMPERES
	up to 200
	200 to 400
	300 to 600
	400 to 700
	600 to 800
	700 to 1000
	800 to 1200

TABLE 11.—APPROXIMATE SPEED OF CUTTING STEEL AND CAST-IRON PLATES

Thickness of Material, in Inches	Current, in Amperes	Cutting Speed, in Inches per Minute
1/4	400	15
3/8	400	12
1/2	400	10
5/8	400	7
3/4	400	4
1	600	3.2
1 1/2	600	2.4
2	600	1.8
3	600	1.1
4	600	0.7
6	800	0.4
8	800	0.3
10	800	0.2
12	800	0.15

TABLE 12.—APPROXIMATE CUTTING SPEEDS OF CAST IRON AND STEEL PLATES WITH COATED ELECTRODES

Plate Thickness, in Inches	Cutting Speeds, in Inches per Minute		
	5/32-Electrode	3/16-Electrode	1/4-Electrode
1/4	12.0	15.0	21.0
1/2	7.0	9.0	11.0
3/4	4.25	5.5	6.7
1	2.5	3.7	4.6
1 1/4	1.6	2.4	3.2
1 1/2	1.0	1.7	2.3
1 3/4	0.6	1.3	1.8
2	0.4	1.0	1.4

Coated electrodes, though more expensive, have certain advantages.

Electric Welding[1]

Electric welding may be subdivided into three kinds: (1) resistance welding, (2) atomic hydrogen welding, and (3) arc welding.

Resistance welding is a heat and squeeze process. The parts to be welded are raised to the temperature of fusion by the passage of a heavy electrical current through the junction. When the welding heat has been reached, pressure is applied mechanically to bring about the union. The field of resistance welding is in turn broken down into several processes, the most important of which are spot welding, butt welding, flash welding, and seam welding.

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[1] Data, Courtesy Lincoln Electric Company, Cleveland, Ohio.

The spot weld is made by overlapping the parts and gripping the overlapped sections between two electrode points through which the current is passed and pressure applied to make the weld in a single spot. The butt weld places the parts to be welded end to end to be heated electrically and squeezed together. The flash weld is an adaptation of the butt weld. The seam weld is similar to the spot weld except that a circular rolling electrode is used to produce the effect of a continuous seam.

In the atomic hydrogen welding process, an alternating-current arc is maintained between two tungsten electrodes, and, at the same time, a stream of hydrogen gas is passed through the arc and around the electrodes. The heat of the arc breaks up the molecules of hydrogen into atoms which recombine outside of the arc to form molecular hydrogen. The very intense heat given off by the atomic hydrogen as it reverts to the molecular form is used to fuse the metals to be welded. The tungsten electrodes do not enter into the weld; they are used only as a means for establishing and maintaining the arc. They are, however, slowly evaporated by the intense heat.

The metal or work being welded does not, as in the metallic arc process of welding, form a part of the electric circuit. Therefore, it does not need to be grounded. The actual manipulation of the electrode holder is similar to the manipulation of the gas torch used in oxyacetylene welding. The flame is played over the edges to be joined, causing them to fuse together. On thick stock, a filler rod may be fused into the weld.

In arc welding, the pieces of metal to be welded are brought to the proper welding temperature at point of contact by the heat liberated at the arc terminals and in the arc stream so that the metals are completely fused into each other, forming a single solid homogeneous mass, after it solidifies.

An electric arc is nothing more than a sustained spark between two terminals or electrodes. In arc welding, the arc is formed between the work to be welded and an electrode held in a suitable holder. The instant the arc is formed, the temperatures of the work at point of welding and the welding electrode jump from normal to the vicinity of 6500°F.

This tremendous heat is concentrated at the point of welding and the end of the electrode. It melts a small pool of metal in the work and heats the end of the electrode. Additional metal required is obtained from the electrode, in the case of a metallic electrode, or by a filler rod which is fed into the arc, melted and deposited. Filler rod may be used with either metallic or carbon electrode.

Metallic Arc Welding.—In the metallic arc process, the arc occurs between the work to be welded and a metallic wire. Under the intense heat developed by the arc, a small part of the work to be welded is brought to the melting point almost instantaneously. The other end of the arc, the tip of the metallic wire, is likewise melted, and tiny globules of molten metal form. Those globules are then forced across the arc and deposited in the molten seat waiting for it in the work. The globules are actually forced across the arc and not dropped as gravity does nothing more than assist this deposition of metal when the work is flat.

It is this fact which permits the use of metallic arc welding in overhead welding.

Carbon Arc Welding.—In carbon arc welding, the arc is formed between the work and a carbon rod held in the electrode holder. The heat of the arc melts a small pool in the surface of the work to be welded. This pool is kept molten by playing the arc across it, and extra metal to form the weld is added by a filler rod. Carbon arc welding is a puddling process and is not applicable to vertical or overhead welding. Its greatest application is in automatic welding or in specialized applications.

The carbon arc may also be used as an economical cutting tool in many cases, particularly where it is desired to dismantle an assembly or to cut risers or where a very smooth cut is unnecessary.

The Shielded Arc.—Molten steel has an affinity for oxygen and nitrogen. Exposed to air, molten steel enters into chemical combination with oxygen and nitrogen to form oxides and nitrides. These impurities tend to weaken and embrittle the steel as well as lessen its resistance to corrosion.

In the ordinary arc, molten globules, which pass from electrode to work, are exposed to ambient atmosphere which contains oxygen and nitrogen. Molten base metal is also exposed to these elements. They combine with the molten metal forming oxides and nitrides. If the metal, during fusion, is completely protected from contact with ambient atmosphere, injurious chemical combination cannot take place. This can be achieved by completely shielding the arc.

An arc may be shielded by completely enveloping it with an inert gas, which will not enter into chemical combination with molten metal and at the same time will prevent contact with the atmospheric oxygen and nitrogen. Welds made with completely shielded arc are largely free of oxides and nitrides and are, therefore, composed of metal having superior physical characteristics to that deposited by an ordinay arc. For example, welds made with a shielded arc have a tensile strength of 60,000 to 75,000 pounds per square inch which is 20 to 50 per cent higher than that possessed by welds deposited by an ordinary arc. Ductility of welds made with a shielded arc averages 100 to 200 per cent greater. Resistance to corrosion of shielded arc welds is greater than that of welds made with an unshielded arc.

Physical Properties of Welds

Physical properties, such as tensile strength, ductility, density, resistance to fatigue, and resistance to impact for weld metals and also for mild rolled steel are given in Table 13.

In manual welding, a shielded arc is obtained through the use of specific types of electrodes that are heavily coated. The heavy coating is of such composition that in the heat of the arc it gives off large quantities of a gas that envelops and completely shields the arc from the ambient atmosphere.

TABLE 13.—PROPERTIES OF WELD METALS AND MILD ROLLED STEEL

Material	Tensile Strength, in Pounds per Square Inch	Ductility, Per Cent Elongation in 2 Inches	Density, in Grams per Cubic Centimeter	Fatigue Resistance,* in Pounds per Square Inch	Impact Resistance, in Foot-Pounds
Weld metal made with bare or washed electrodes.	40,000 to 55,000	5 to 10	7.5 to 7.7	12,000 to 15,000	8 to 15 (Izod)
Weld metal made with shielded arc.	65,000 to 75,000	20 to 30	7.84 to 7.86	28,000 to 32,000	50 to 80 (Izod)
Mild rolled steel. . . .	55,000 to 65,000	20 to 30	7.86	28,000	40 to 80 (Izod)

* Maximum stress in outside fibers, 10 million reversals without failure. Rotating beam test.

The action of the arc on the coating of the electrode results in a slag formation which floats on top of the molten weld metal and protects it from the ambient atmosphere while cooling. After the weld metal is sufficiently cooled, the slag may be easily removed.

In automatic welding, a completely shielded arc can be obtained in the carbon arc process by the introduction of a specially prepared substance into the arc flame at the point of fusion. The combustion of this substance in the arc provides an inert gas which completely encloses and shields the arc from the ambient atmosphere. Another form of shield is obtained by automatic deposition of powder on the joint ahead of the arc. The arc penetrates through the powder to weld the joint. In addition to the inert gas formed, a slag is produced which floats on top of the molten metal and protects it from the atmosphere while cooling.

General Suggestions Regarding Arc Welding

Preparation of the Work.—The work to be welded should be clean, preferably free from corrosion, oil, water, and other foreign matter. To facilitate welding, the work should be placed, where possible, in such a position that flat welds can be made. The next best position is that requiring vertical or overhead welds. Work in a position requiring horizontal welds is least preferable because welds in this location require more time and care in their making; but the physical qualities of such welds are equal to those made in other positions.

Length of Arc.—Arc length is the distance between the end of the electrode and the surface upon which the molten globules are deposited. The correct length of the arc will vary, depending upon the size and type of electrodes used, the material to be welded and amount of welding heat, and other regulating factors involved in the welding process employed. The ordinary or unshielded arc should be short for best results. An important reason for this is that the globules of molten electrode metal in process of deposition may have the smallest possible opportunity for contact with the ambient atmosphere and will absorb from it a minimum of oxygen and nitrogen. These instructions do not apply when welding with a shielded arc. It has been found that the correct length of the shielded arc is longer. The heavy coating of the electrodes employed with the shielded arc is not consumed so rapidly as the electrode metal melts. The resultant projection of coating focuses a concentrated arc stream, although the actual length of the arc is longer.

Skip Welding.—Skip welding is a very effective way to prevent distortion and reduce locked-up stresses. This method consists in keeping the expanding zones sufficiently narrow and sufficiently close to the contracting zones so that they tend to stress-relieve or neutralize each other. This can be accomplished by making a short weld, then skipping some distance ahead, making another similar short weld, etc., and then returning to the first weld and making another weld adjacent to it. Sufficient time should elapse between making adjacent welds so that the first weld is sufficiently cool and is in contraction.

Step-Back Method of Welding.—The step-back method of welding is a method of distribution of welds and procedure of making welds to help prevent the accumulation of stresses and distortion. This method consists not only of breaking up the welds in short sections but is dependent also upon welding in the proper direction. The welds may be made in sequence or may be broken up.

Polarity of Welding Current.—The polarity of the welding current is sometimes spoken of as "straight" or "reverse." In "straight" polarity, the electrode is negative, and the work positive; in "reversed" polarity, the electrode is positive, and the work negative. Electrode negative is used in welding with bare or lightly coated electrodes, because with such electrodes somewhat more heat is generated on the positive side of the circuit. However, the addition of a coating to the electrode forms gases in the arc and the presence of these gases may alter the heat conditions so that the opposite is true; namely, the greater heat is produced on the negative side.

Both polarities are frequently used. The polarity to use with a particular electrode is established by the electrode designer. When doubt exists as to the correct polarity to use, the burn-off rate of the electrode will serve as a good guide. Each polarity is used to burn off 6 or 8 inches of electrode. The polarity that results in the longer burn-off time is generally the one that produces greater heat in the plate or joint. This is desirable in some cases, but in others it is desirable to use the polarity that produces less heat in the plate.

Steels of Good Weldability.—The importance of using steel of good welding quality increases in proportion to the amount of base metal entering into the weld.

General-purpose steel, the analysis of which immediately follows, is the best for arc welding at high speeds and should be used in all cases where physical requirements permit. In cases where the steel will be required to withstand considerable drawing or forming or to have special finish or special physical properties, some modifications of these specifications may be necessary, and the steel manufacturer should be consulted.

TABLE 14.—ANALYSIS OF GENERAL-PURPOSE STEEL

Material Added	Per Cent Recommended	Per Cent Limits
Carbon	0.17	0.15 to 0.25
Manganese	0.45	0.35 to 0.60
Silicon	0.05	0.07 maximum
Sulphur	low	0.05 maximum
Phosphorus	low	0.045 maximum
Aluminum	Not over 2 ounces per ton added to steel unless it has been semikilled with silicon,* in which case the aluminum addition should be as low as practical. For this classification steel can be considered semikilled with silicon if the silicon content is between 0.04 and 0.07 per cent.	

* If silicon is added prior to the aluminum addition in the proper ratio, the nonmetallic inclusions coming out of the steel during welding will have sufficiently low melting point to be self-fluxing and will not form slag pockets along the edge of the welds. The addition of aluminum or of vanadium seems to have a beneficial effect in reducing the tendency toward porosity of welds in silicon-killed steels.

Types of Joints for Arc Welding

BUTT JOINTS

1. **Plain Butt Joint.**—Largely used on plates up to ⅜ inch thick with metal electrode and ¾ inch with carbon electrode, although generally used below this. Inexpensive as to preparation of joint. Suitable for all usual load conditions if full penetration is secured.

2. **Single-V Butt Joint.**—Used largely for ⅜-inch plate or thicker. Scarfing and machining cost more than (1), and more electrode used than in (1). Used generally on plates thicker than in (1). Meets all general or usual load conditions.

3. **Double-V Butt Joint.**—The cost of machining is greater, but less weld metal is used than in (2). Cost of machining and welding should be balanced against each other. Used largely for ½ inch and heavier, and for all usual loads. (Note that joint is welded from both sides.)

4. **Single-U Butt Joint.**—Generally used on plates heavier than preceding, that is, ½ inch, ¾ inch, and over. Costs more to machine than single V, but requires less electrode. Is welded from one side, except a single bead, which is put in last on opposite side. Meets all usual load conditions. Usually used for best quality work.

5. **Double-U Butt Joint.**—Used where welds can be made from both sides, that is, in plate sizes usually heavier than in (4) and where the saving in electrode used justifies the greater machining cost as compared to double V. Used in all types of loads.

6. **Plain Fillet-Welded Tee Joint.**—May be used for all ordinary plate sizes. No machining of plates. Most satisfactory when welds are in longitudinal shear. For welds heavily loaded transversely by fatigue or severe impact, use with caution.

7. **Single-V Tee Joint.**—This is better than (6). For work welded from one side. Generally used on ½-inch plates or lighter. Costs more for joint preparation but uses less electrode than (6). For more severe load conditions as outlined in (6).

8. **Double-V Tee Joint.**—Used for heavy plates. Welded from both sides. Uses less electrode than (6). May be used for severe longitudinal or transverse loads of all kinds.

9. **Single-U Tee Joint.**—For usual size plates, generally 1 inch and heavier. Welded from one side only. Advisable to put in a final finish bead on side away from the U. Machining costs more, but takes less electrode than single V. For same load conditions as given under single V (7).

10. **Double-U Tee Joint.**—For plates generally 1½ inch and heavier which can be welded from both sides. More expensive preparation, but uses less electrode than (8). For all load conditions, even very severe.

CORNER JOINTS

11. **Flush Corner Joint.**—Generally used for 12 gage and lighter. May be used for heavier plates with caution. Not for very severe loads on heavier plate.

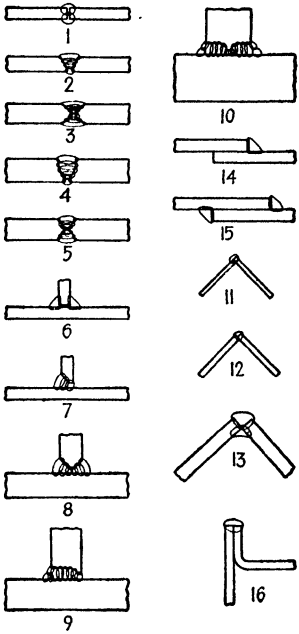
12. **Half-Open Corner Joint.**—Generally used for 12 gage or heavier, where welded from one side only. "Shouldering" effect reduces probability of burning-through and makes for easy welding. May be used for ordinary loads, but with caution for fatigue or impact loads.

13. **Full-Open Corner Joint.**—Used for all plate thickness when welds can be made from both sides. May be used under severe load conditions, for maximum strength.

LAP JOINTS

14. **Single-Bead Lap Joint.**—May be used for all sizes of plates where joints are not subject to excessive fatigue or high impact loads.

15. **Double-Bead Lap Joint.**—Better than (14). May be used for load conditions, more severe than single-bead lap joint. Beads should be full size, and joints may be loaded much more severely than (14). The butt joints (1) to (5) are the best joints for very severe service, but, of course, are more expensive.



Butt, Corner, Lap, and Edge Joints

EDGE JOINT

16. **Edge Joint.**—Generally used for ¼ inch or thinner. Not recommended for heavier work. For loads which are not very severe.

Suggestions for Arc Welding Cast Iron

Each job should be studied carefully before welding in order to avoid possible difficulties arising from uneven expansion and contraction of the casting. The heat of the welding arc is confined to a comparatively small area, and for this reason complicated castings offer less trouble when welding is done with the arc than by other methods. For this same reason, many gray-iron castings can be arc-welded in place without dismantling for preheating.

It is evident that the greater the length of the weld in a straight length, the greater the strain, since the strain is cumulative. Therefore, if a bead is curved, there is a tendency to reduce this cumulative effect.

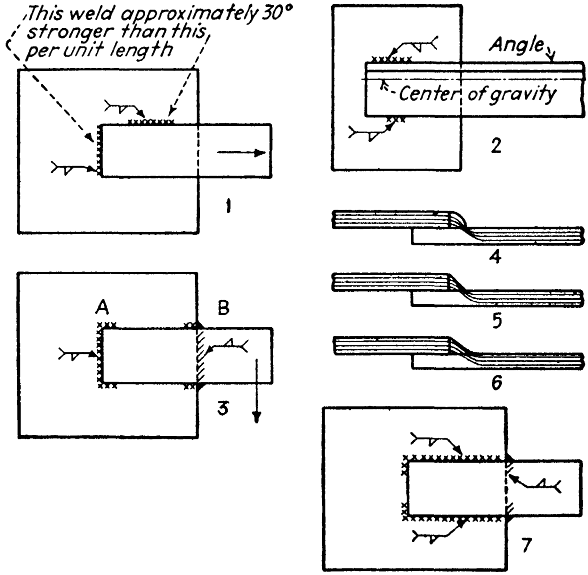
TABLE 15.—LENGTH OF FILLET WELD TO REPLACE RIVETS

Rivet Diameter Size, in Inches	Rivet Shear Value at 12,000 Pounds per Square Inch	Length of Fillet Welds, to Nearest 1/8 Inch									
		1/4-Inch Bead		5/16-Inch Bead		3/8-Inch Bead		1/2-Inch Bead		5/8-Inch Bead	
		"Fusion Code"	Shielded Arc	"Fusion Code"	Shielded Arc	"Fusion Code"	Shielded Arc	"Fusion Code"	Shielded Arc	"Fusion Code"	Shielded Arc
1/2	2356	1 1/2	1 1/4	1 1/4	1	1	7/8	7/8	3/4	3/4	5/8
5/8	3682	2 1/8	1 3/4	1 3/4	1 3/8	1 1/2	1 1/4	1 1/8	1	1	7/8
3/4	5301	3	2 3/8	2 3/8	2	2	1 3/4	1 1/2	1 1/4	1 3/8	1 1/8
7/8	7216	3 7/8	3 1/8	3 1/8	2 1/2	2 5/8	2 1/8	2	1 3/4	1 3/4	1 3/8
1	9425	5	4	4	3 1/4	3 3/8	2 3/4	2 5/8	2 1/8	2 1/8	1 3/4

NOTE.—One-fourth inch is added to calculated length of bead for starting and stopping the arc.

Another method is to deposit weld metal in short lengths and allow each to cool. For example, weld ½ minute, and then allow the weld to cool for 3 to 5 minutes. By depositing small welds in various parts of the job, one weld is allowed to cool while metal is deposited in another location.

The third method is to upset or peen the deposited weld metal lightly while it is still hot, before it has a chance to cool and contract. This causes the weld metal to stretch. In many cases the best method to pursue is to use a combination of the three methods just described.


This weld approximately 30° stronger than this, per unit length
1
Angle
Center of gravity
2
A
B
3
4
5
6
7

Other Examples of Welds

The weld metal deposited by the electric-arc process in cast iron is generally far stronger than the cast-base metal. When steel electrode is used, the weld metal is generally three to four times as strong as the casting.

Coated electrodes of the proper type are usually designed to keep the amount of heat required to a minimum, thus reducing thermal disturbance and resultant hardness.

Usually ⅛-inch size electrodes are used for keeping the heat down as mentioned above. Electrode is made positive, work negative, and the current is approximately 80 amperes. This apparently too low current is employed to satisfy the heat conditions previously mentioned. The electrode itself will carry considerably more current, but the requirements of cast-iron welding make the use of greater heat inadvisable.

The electrode to use in cast iron is a coated electrode with steel base. It provides a solid, dense weld on cast iron of greater tensile strength than the cast iron itself. It affords an excellent bond or union with the cast iron. Because of the low current used, the hardening effect usually present along the line of fusion is materially reduced, the resultant weld being, therefore, much more machinable than is usually the case where other electrodes are employed.

The welding of cast iron should be done very intermittently. In some cases, "skip" welding is used with a weld not over 3 inches made at one time. Immediately after each bead is deposited it should be lightly peened, thoroughly cleaned, and allowed to cool before the next bead is applied. Care should be taken to keep the work clean and not allow it to get too hot. A good rule in reference to cast iron is: *Keep the work clean and cold.*

The chilling action of the cast iron increases the combined carbon and in turn increases the hardness and brittleness, weakening the strength of the cast iron just back of the line of fusion. Welds in cast iron, if of sufficient thickness, may be strengthened by the mechanical method of studding.

Studs of steel approximately $\frac{1}{4}$ to $\frac{3}{8}$ inches in diameter should be used. The cast iron should be V-d and drilled and tapped along the V so that the studs may be screwed into the casting. The studs should project about $\frac{3}{16}$ to $\frac{1}{4}$ inch above the cast-iron surface. The studs should be long enough to be screwed into the casting to a depth of at least the diameter of the studs.

The cross-sectional area of the studs should be about 25 to 35 per cent of the area of the weld surface. In such cases the strength of the weld may safely and conservatively be taken as the strength of the studs. It is considered good practice first to weld one or two beads around each stud, making sure that fusion is obtained with both the stud and cast-iron base metal.

Straight lines of weld metal should be avoided so far as possible. Welds should be deposited intermittently, and each bead peened before cooling. This is advisable where the casting is of sufficient thickness to vee from both sides and stud. In many cases it may be desirable to produce complete penetration at the fracture.

In some cases it may be practical and more desirable to shape out grooves in the casting with a round-nosed tool instead of studding.

Welded Jigs and Fixtures

Many jigs and fixtures can be made quicker and cheaper by welding standard steel bars and plates than by using castings. The savings are said to run up to 40 per cent in some cases, with an average of half that amount. Fixtures must, however, be designed for welding. Aluminum and magnesium are also being used for fixtures where light weight is necessary or desirable for ease in handling. The following suggestions are based on long experience.

1. Welds in transverse shear are stronger than welds in longitudinal shear.
2. Lengths of welds proportioned to loading provide better load distribution results.

3. Placement of welds to resist turning effect of one member of the joint.
4. Example of lap weld having poor distribution of stress through weld. Satisfactory for many jobs, though (5) and (6) are better.
5. Example of lap weld having a more even distribution of stress through weld. Better than (4) and more commonly used.
6. Example of lap weld in which there is fairly uniform transfer of stress through the weld. Better than (4) and (5) for severe fatigue and impact, but more expensive.
7. Example of welds hooked around the corners to obtain resistance to tearing action on welds when subjected to eccentric loads.

METALLIZING OR METAL SPRAYING

Although the spraying of metal coatings on surfaces of many kinds has been known for years the process is just becoming recognized as a practical shop operation. It is used for protection against corrosion or decay and for building up surfaces that are too small because of wear or other reasons. In this field it competes with flame or arc welding. The characteristics of both processes make one more suitable for some kinds of work than the other.

Metallizing, as its name implies, is a process for spraying pure metal on practically any metallic or nonmetallic surface without the use of acid or flux or without preheating the object to be coated. The spray gun is a small device weighing about four pounds, having within it a power plant which consists of an air turbine connected to reducing gears and feed rollers for automatically feeding wire through the gun to a nozzle which is supplied with oxygen and acetylene, much the same as a welding or blowtorch. When the wire is pulled through the gun by the feed rollers, it comes into contact with the oxyacetylene flame and is melted.

The molten metal is then blown by compressed air at high velocity onto the surface to be coated. If the surface is of a porous nature, then the molten particles of metal will be impacted into it and key fast without any special preparation. To coat a metal surface, it is first necessary to sand blast or steel-grit blast thoroughly in order to produce a roughened surface with sharp elevations and undercuts. When the atomized molten particles of metal are directed onto this surface, they key or dovetail to it and the coatings are tightly locked to the metal base.

The metallized surface can be built up to any reasonable thickness desired and can be filed, ground, or polished just as a sheet of metal. If cut with a tool, the tool should be very sharp. A dull tool is more apt to tear the coating from the base metal.

LEAD BURNING

The operation known as "lead burning" is really lead welding. Shops handling storage-battery repairs find the oxyacetylene blowpipe useful in this work. The most important property of lead is its low melting point. A very small flame with a slight excess of acetylene is required.

Hold the blowpipe so that the flame is almost perpendicular to the surface of the work, with the inner cone almost touching the metal. Heat the lead until it just melts, then lift the blowpipe quickly in order to prevent excess melting. In this way it is possible to control this easily fused metal. The welding rod may be made by cutting sheet lead into strips or by melting some lead and molding it into rods of convenient size. In adding metal from the rod, the Linde Air Products Company says, the blowpipe flame should be played simultaneously on the rod and along the edges of the work to be welded so that they will reach the fusion point at the same time. Thorough fusion is as important in lead welding as it is in welding steel.

It is sometimes impossible to burn on a connector or terminal in one complete operation because the metal surrounding the cavity becomes overheated. In this case, stop work as often as the lead seems to be running too rapidly, and allow it to cool before proceeding.

In most work with sheet lead, such as tank linings, lap joints are used, with a well-cleaned overlap of ¼ to ½ inch. Often forms are necessary to support the sheet. After the lap is in position, the joint should be tapped slightly with a wooden mallet in order to cause closer contact of the sheets. Each edge of the lap is then fillet-welded, using rod. When it is not possible to work from both sides, for example, when a lining must be made in place, the butt weld is preferable. The lead sheets must then be supported in position and tack-welded to maintain alignment. Vertical seams should be started at the bottom so that the work progresses upward.

SPREADING LOCOMOTIVE FRAMES FOR WELDING

The same condition does not exist in every frame weld. Some 4 by 4-inch frames require more expansion than other frames of the same dimension, owing to the location of the break or its relation to some section of the locomotive where more strength is required. When a frame is hard to expand because of its location or because it is closely coupled at the point of fracture, it is very necessary that the expansion be increased a small amount to take care of the contraction that takes place more rapidly when the spreading device is taken out.

Frame welds are being made with manganese bronze on some roads to avoid the necessity of heating as much as where steel rods are used.

Table 16 gives the amount frames to be welded should be spread, the figures being based on experience.

TABLE 16.—AMOUNT OF SPREAD FRAMES SHOULD BE GIVEN FOR WELDING

FRAME SECTION IN INCHES	INCH SPREAD TO BE ALLOWED
3 × 4	$\frac{1}{4}$
4 × 4	$\frac{5}{16}$
4 × 4½	$\frac{11}{32}$
4 × 5	$\frac{3}{8}$
5 × 6	$\frac{13}{32}$
6 × 8	$\frac{7}{16}$
6 × 9	$\frac{1}{2}$
8 × 8	$\frac{1}{2}$

From a paper presented at the October, 1923, meeting, Chicago Section, American Welding Society.

Welding Locomotive Frames by Thermit

When fracture is between jaws they must be spread by using screw jack or other form of spreader. The gap should be opened from 3/16 to 5/16 inch, depending on the size of the frame and the amount of preheating. The longer the preheating, the more the heat soaks back into the frame and the greater must be the allowance for contraction. The jack should not be removed too soon—about ½ hour after weld is made is a good average.

Cast-iron thermit welds are hard to machine because the cast iron used contains over 3 per cent carbon and makes a high carbon steel in the weld. If finishing is necessary, it is usually done by grinding. Welds in wrought iron and steel machine more readily.

Metals That Can Be Welded

Since all metals do not weld together satisfactorily, the following table will be found convenient. Aluminum, for example, welds only to aluminum, tin plate, and zinc. Lead can be joined only to lead, galvanized iron, tin plate, zinc, and nickel silver.

TABLE 17.—COMBINATIONS OF METALS THAT CAN BE WELDED SUCCESSFULLY

METALS	Aluminum	Ascoloy	Brass	Copper	Galv. iron	Iron	Lead	Monel	Nickel	Nichrome	Tin plate	Zinc	Phos. bronze	Nickel silver
Aluminum	○										○	○		
Ascoloy		○	○	○	○	○		○	○	○	○		○	○
Brass		○	○	○	○	○		○	○	○	○	○	○	○
Copper		○	○	○	○	○		○	○	○	○	○	○	○
Galv. iron		○	○	○	○	○	○	○	○	○	○		○	○
Iron		○	○	○	○	○		○	○	○	○		○	○
Lead					○		○				○	○		○
Monel		○	○	○	○	○		○	○	○	○		○	○
Nickel		○	○	○	○	○		○	○	○	○		○	○
Nichrome		○	○	○	○	○		○	○	○	○		○	○
Tin plate	○	○	○	○	○	○	○	○	○	○	○		○	○
Zinc	○		○	○			○					○		
Phos. bronze		○	○	○	○	○		○	○	○	○		○	○
Nickel silver		○	○	○	○	○	○	○	○	○	○		○	○

The Al-Fin Process of Joining Aluminum and Steel

The Al-Fin process is a method of bonding an aluminum muff or sleeve on a steel cylinder barrel with a ferric-aluminum bond that is stronger than pure aluminum. This is claimed to be a 100 per cent bond, far in excess of that obtained by the usual shrinking process. The thickness of the bond as at present applied is given as 0.004 inch. This is a process developed by the Fairchild Engine and Airplane Company and handled by their subsidiary, the Al-Fin Corp.

SECTION VIII

GEARING

SHAPES OF GEAR TEETH

Cycloidal or Epicycloidal.—A curved tooth generated by the point of a circle rolling away from the gear wheel or rack.

Involute.—A curved tooth generated by unwinding a tape or string from a cylinder. The rack tooth has straight sides.

Involute Standard.—The standard gear tooth has a 14½-degree pressure angle which means that the teeth of a standard rack have straight sides 14½ degrees from the vertical.

Involute—Stubbed.—A tooth shorter than the standard and usually with a 20-degree pressure angle.

Addendum.—Length from pitch line to outside.

Chordal Pitch.—Distance from center to center of teeth in a straight line.

Circular Pitch.—Distance from center to center of teeth measured on the pitch circle.

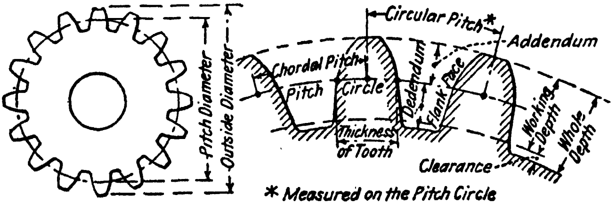


FIG. 1.—Parts of Gear Teeth

Clearance.—Extra depth of space between teeth.

Coast Side of Tooth.—The back of tooth.

Drive Side of Tooth.—The side that drives.

Dedendum.—Length from pitch line to base of tooth.

Diametral Pitch.—Number of teeth divided by the pitch diameter or the teeth to each inch of pitch diameter.

Face.—Working surface of tooth above pitch line.

Flank.—Working surface of tooth below pitch line.

Outside Diameter.—Total diameter over teeth.

Pitch Diameter.—Diameter at the pitch line.

Pitch Line.—Line of contact of two cylinders which would have the same speed ratios as the gears.

Linear Pitch.—Sometimes used in rack measurement. Same as circular pitch of a gear.

Twelve types of gears, most of them in common use, are shown in Fig. 2.

Gears are cut by several methods. The oldest and most common is to mill the teeth with formed cutters, indexing the gear blank for each tooth. In gear hobbing, the cutter resembles a tap, and the gear blank revolves continuously at the proper rate, as the hob feeds across the face of the gear.

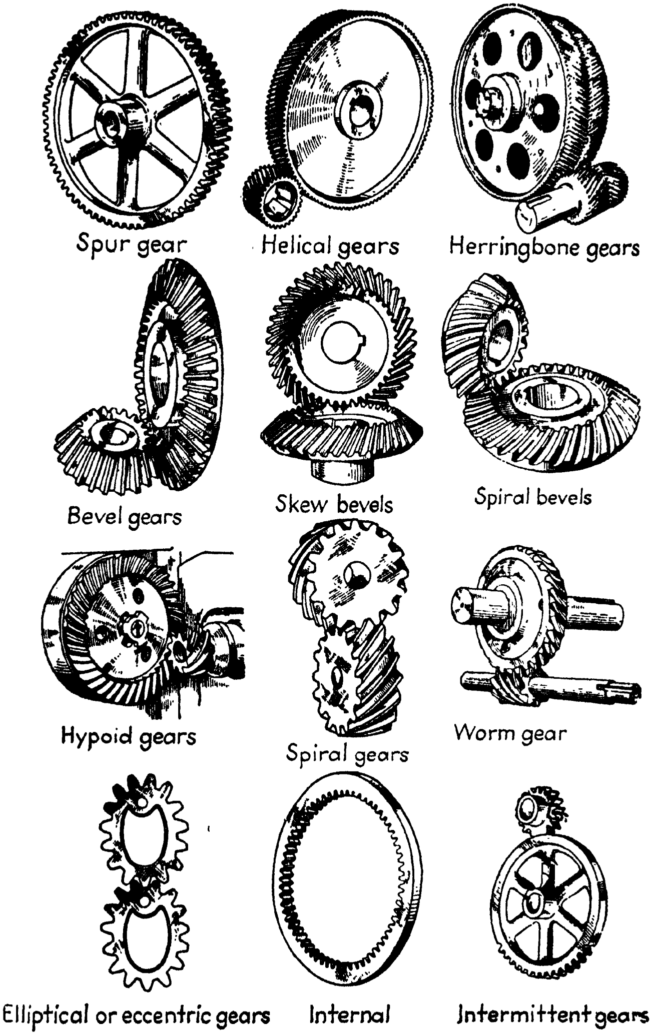


FIG. 2.—Twelve Types of Gears

Gears are also cut by shaping or planing, a form tool being used in some few cases. Gear shaping, however, as with the Fellows, Maag, and Sykes methods, is a tooth-generating process as is hobbing. In the Fellows and Sykes machines the cutter is practically a hardened gear and both the cutter and gear blank turn at the proper rate so that the tooth curves are generated. The Maag process uses a cutter in the form of a rack, but the teeth are generated in a similar way.

Herringbone gears are double helical gears with the helix angles running in opposite directions. When made in one piece, they commonly have a groove in the center to permit the tool or cutter to run out without gashing the other teeth. The Sykes machine, however, cuts both angles without the necessity of the center groove.

Gear-teeth forms are being modified to suit special conditions. Teeth are strengthened on pinions with few teeth by shifting the pitch line nearer the center, making a short dedendum and a long addendum, *using generating cutters only.* The outside diameter of the pinion is increased and the outside diameter of the gear decreased by the same amount. Teeth are cut to standard depth in both blanks. This prevents undercutting the teeth in the pinion. Ordinary formed gear cutters cannot be used for this.

Spiral bevel gears, developed by the Gleason Works, have teeth that approximate a spiral and are designed to give a continuous contact to secure a steady and quiet drive. They are used almost universally in automobile drives and to some extent elsewhere. They can be cut only on special machines of the same company.

Hypoid gears are a modification of the spiral bevel in which the pinion is located below or above the center of the mating gears. The action more nearly approaches that of a worm drive and the location of the pinion permits its shaft to extend beyond the gear for support or other reasons.

FORMULAS FOR GEARING

Having	To Get	Rule	Formula
The Diametral Pitch	The Circular Pitch	Divide 3.1416 by the Diametral Pitch	$P' = \frac{3.1416}{P}$
The Pitch Diameter and the Number of Teeth ...	The Circular Pitch	Divide Pitch Diameter by the product of .3183 and Number of Teeth	$P' = \frac{D'}{.3183\,N}$
The Outside Diameter and the Number of Teeth ...	The Circular Pitch	Divide Outside Diameter by the product of .3183 and Number of Teeth plus 2	$P' = \frac{D}{.3183(N+2)}$
The Number of Teeth and the Circular Pitch	Pitch Diameter	The continued product of the Number of Teeth, the Circular Pitch and .3183	$D' = NP'\ .3183$
The Number of Teeth and the Outside Diameter ...	Pitch Diameter	Divide the product of Number of Teeth and Outside Diameter by Number of Teeth plus 2	$D' = \frac{ND}{N+2}$
The Outside Diameter and the Circular Pitch	Pitch Diameter	Subtract from the Outside Diameter the product of the Circular Pitch and .6366	$D' = D - (P'.6366)$
Addendum and the Number of Teeth ...	Pitch Diameter	Multiply the Number of Teeth by the Addendum	$D' = Ns$
The Number of Teeth and the Circular Pitch	Outside Diameter	The continued product of the Number of Teeth plus 2, the Circular Pitch and .3183	$D = (N+2)\ P'\ .3183$
The Pitch Diameter and the Circular Pitch	Outside Diameter	Add to the Pitch Diameter the product of the Circular Pitch and .6366....	$D = D' + (P'.6366)$
The Number of Teeth and the Addendum........	Outside Diameter	Multiply Addendum by Number of Teeth plus 2	$D = s\ (N+2)$
The Pitch Diameter and the Circular Pitch	Number of Teeth	Divide the product of Pitch Diameter and 3.1416 by the Circular Pitch	$N = \frac{D'3.1416}{P'}$
The Circular Pitch	Thickness of Tooth	One half the Circular Pitch	$t = \frac{P'}{2}$
The Circular Pitch	Addendum	Multiply the Circular Pitch by .3183 or $s = \frac{D'}{N}$	$s = P'\ .3183$
The Circular Pitch	Root	Multiply the Circular Pitch by .3683	$s + f = P'\ .3683$
The Circular Pitch	Working Depth	Multiply the Circular Pitch by .6366	$D'' = P'\ .6366$
The Circular Pitch	Whole Depth	Multiply the Circular Pitch by .6866	$D'' + f = P'\ .6866$
The Circular Pitch	Clearance	Multiply the Circular Pitch by .05	$f = P'\ .05$
Thickness of Tooth	Clearance	One tenth the Thickness of Tooth at Pitch Line	$f = \frac{t}{10}$

FORMULAS FOR GEARING

Having	To Get	Rule	Formula
The Circular Pitch	The Diametral Pitch	Divide 3.1416 by the Circular Pitch	$P = \frac{3.1416}{P'}$
The Pitch Diameter and the Number of Teeth ...	The Diametral Pitch	Divide Number of Teeth by Pitch Diameter	$P = \frac{N}{D'}$
The Outside Diameter and the Number of Teeth	The Diametral Pitch	Divide Number of Teeth plus 2 by Outside Diameter	$P = \frac{N+2}{D}$
The Number of Teeth and the Diametral Pitch	Pitch Diameter	Divide Number of Teeth by the Diametral Pitch	$D' = \frac{N}{P}$
The Number of Teeth and the Outside Diameter......	Pitch Diameter	Divide the Product of Outside Diameter and Number of Teeth by Number of Teeth plus 2	$D' = \frac{DN}{N+2}$
The Outside Diameter and the Diametral Pitch ...	Pitch Diameter	Subtract from the Outside Diameter the quotient of 2 divided by the Diametral Pitch.................	$D' = D - \frac{2}{P}$
Addendum and the Number of Teeth ...	Pitch Diameter	Multiply Addendum by the Number of Teeth	$D' = s\,N$
The Number of Teeth and the Diametral Pitch	Outside Diameter	Divide Number of Teeth plus 2 by the Diametral Pitch.................	$D = \frac{N+2}{P}$
The Pitch Diameter and the Diametral Pitch	Outside Diameter	Add to the Pitch Diameter the quotient of 2 divided by the Diametral Pitch	$D = D' + \frac{2}{P}$
The Pitch Diameter and the Number of Teeth ...	Outside Diameter	Divide the Number of Teeth plus 2, by the quotient of number of Teeth divided by Pitch Diameter	$D = \frac{N+2}{\frac{N}{D'}}$
The Number of Teeth and Addendum ..	Outside Diameter	Multiply the Number of Teeth plus 2 by Addendum	$D = (N+2)\,s$
The Pitch Diameter and the Diametral Pitch	Number of Teeth	Multiply Pitch Diameter by the Diametral Pitch	$N = D'\,P$
The Outside Diameter and the Diametral Pitch	Number of Teeth	Multiply Outside Diameter by the Diametral Pitch and subtract 2	$N = DP - 2$
The Diametral Pitch	Thickness of Tooth	Divide 1.5708 by the Diametral Pitch	$t = \frac{1.5708}{P}$
The Diametral Pitch	Addendum	Divide 1 by the Diametral Pitch or $s = \frac{D'}{N}$	$s = \frac{1}{P}$
The Diametral Pitch	Root	Divide 1.157 by the Diametral Pitch	$s + f = \frac{1.157}{P}$
The Diametral Pitch	Working Depth	Divide 2 by the Diametral Pitch.................	$D'' = \frac{2}{P}$
The Diametral Pitch	Whole Depth	Divide 2.157 by the Diametral Pitch	$D'' + f = \frac{2.157}{P}$
The Diametral Pitch	Clearance	Divide .157 by the Diametral Pitch................	$f = \frac{.157}{P}$
Thickness of Tooth	Clearance	Divide Thickness of Tooth at pitch line by 10......	$f = \frac{t}{10}$

TABLE 1.—INVOLUTE TOOTH PARTS
(Dimensions in Inches)

Diametral Pitch, P	Circular Pitch, p, $\frac{3.1416}{P}$	Thickness of Tooth at Pitch Diameter T, $\frac{1.5708}{P}$	Addendum, a, $\frac{1}{P}$	Working Depth, h, $\frac{2}{p}$	Whole Depth Spur Gears, Worms, Worm Gears, $\frac{2.157}{P}$
½	6.2832	3.1416	2.0000	4.0000	4.3140
¾	4.1888	2.0944	1.3333	2.6667	2.8760
1	3.1416	1.5708	1.0000	2.0000	2.1570
1¼	2.5133	1.2566	0.8000	1.6000	1.7256
1½	2.0944	1.0472	0.6667	1.3333	1.4380
1¾	1.7952	0.8976	0.5714	1.1429	1.2326
2	1.5708	0.7854	0.5000	1.0000	1.0785
2¼	1.3963	0.6981	0.4444	0.8889	0.9587
2½	1.2566	0.6283	0.4000	0.8000	0.8628
2¾	1.1424	0.5712	0.3636	0.7273	0.7844
3	1.0472	0.5236	0.3333	0.6667	0.7190
3½	0.8976	0.4488	0.2857	0.5714	0.6163
4	0.7854	0.3927	0.2500	0.5000	0.5393
5	0.6283	0.3142	0.2000	0.4000	0.4314
6	0.5236	0.2618	0.1667	0.3333	0.3595
7	0.4488	0.2244	0.1429	0.2857	0.3081
8	0.3927	0.1964	0.1250	0.2500	0.2696
9	0.3491	0.1745	0.1111	0.2222	0.2397
10	0.3142	0.1571	0.1000	0.2000	0.2157
11	0.2856	0.1428	0.0909	0.1818	0.1961
12	0.2618	0.1309	0.0833	0.1667	0.1798
14	0.2244	0.1122	0.0714	0.1429	0.1541
16	0.1964	0.0982	0.0625	0.1250	0.1348
18	0.1745	0.0873	0.0556	0.1111	0.1198
20	0.1571	0.0785	0.0500	0.1000	0.1079
22	0.1428	0.0714	0.0455	0.0909	0.0980
24	0.1309	0.0654	0.0417	0.0833	0.0899
26	0.1208	0.0604	0.0385	0.0769	0.0830
28	0.1122	0.0561	0.0357	0.0714	0.0770
30	0.1047	0.0524	0.0333	0.0667	0.0753
32	0.0982	0.0491	0.0312	0.0625	0.0708
36	0.0873	0.0436	0.0278	0.0556	0.0631
40	0.0785	0.0393	0.0250	0.0500	0.0570
44	0.0714	0.0357	0.0227	0.0455	0.0520
48	0.0654	0.0327	0.0208	0.0417	0.0478
50	0.0628	0.0314	0.0200	0.0400	0.0460
56	0.0561	0.0280	0.0179	0.0357	0.0413
60	0.0524	0.0262	0.0167	0.0333	0.0387
64	0.0491	0.0245	0.0156	0.0312	0.0364
72	0.0436	0.0218	0.0139	0.0278	0.0326
80	0.0393	0.0196	0.0125	0.0250	0.0295

NOTE.—The American Gear Manufacturers Association, Empire Building, Pittsburgh, Pa., recommends a whole depth of $\frac{2.200}{P}$ + 0.002 inch for gears from 30p to 200P.

STANDARD COMPOSITE GEAR-TOOTH SYSTEMS

Committees of the American Standards Association have worked out the following systems for gear-tooth forms which were approved in January, 1927.

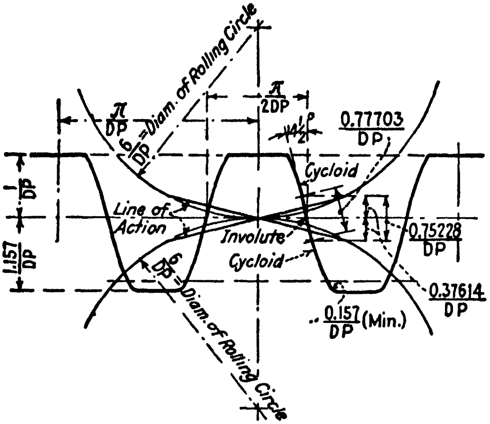


FIG. 3.—Basic Rack for 14½-Degree Composite System (Full-Depth Tooth)

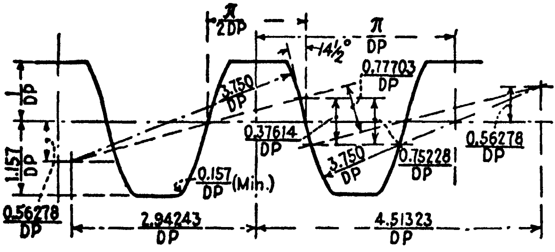


FIG. 4.—Approximation to Basic Rack for 14½-Degree Composite System (Full-Depth Tooth)

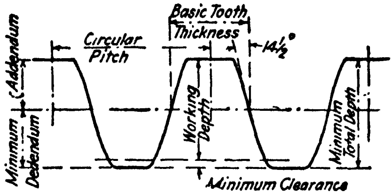


FIG. 5.—Full-Depth Tooth Proportions for Spur Gears—14½-Degree Composite System

The use of both diametral and circular pitches:[1]

	IN TERMS OF DIAMETRAL PITCH, IN.	IN TERMS OF CIRCULAR PITCH, IN.
1. Addendum	$= \frac{1}{D.P.}$	$= 0.3183 \times C.P.$
2. Minimum dedendum[2]	$= \frac{1.157}{D.P.}$	$= 0.3683 \times C.P.$
3. Working depth	$= \frac{2}{D.P.}$	$= 0.6366 \times C.P.$
4. Minimum total depth[2]	$= \frac{2.157}{D.P.}$	$= 0.6866 \times C.P.$
5. Pitch diameter	$= \frac{N.}{D.P.}$	$= 0.3183 \times N. \times C.P.$
6. Outside diameter	$= \frac{N. + 2}{D.P.}$	$= 0.3183 \times (N. + 2) \times C.P.$
7. Basic tooth thickness on pitch line	$= \frac{1.5708}{D.P.}$	$= 0.5 \times C.P.$
8. Minimum clearance[2,3]	$= \frac{0.157}{D.P.}$	$= 0.05 \times C.P.$

[1] N = number of teeth. D.P. = diametral pitch. C.P. = circular pitch. The term diametral pitch is used up to 1 D.P. inclusive and the term circular pitch is used for 3 in. C.P. and over.

[2] A suitable working tolerance should be considered in connection with all minimum recommendations.

[3] Minimum clearance refers to the clearance between the top of the gear tooth, and the bottom of the mating gear space, and is specified as "minimum" so as to allow for necessary cutter clearance for all methods of producing gears. At the present time this value has not been standardized.

20-DEGREE STUB INVOLUTE SYSTEM

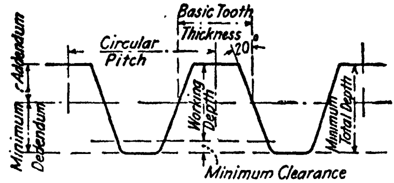


FIG. 6.—Basic Rack for 20-Degree Stub Involute System for Spur Gears

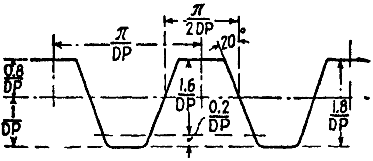


FIG. 7.—Proportions for Spur Gears

The use of both diametral and circular pitches:[1]

	IN TERMS OF DIAMETRAL PITCH, IN.	IN TERMS OF CIRCULAR PITCH, IN.
1. Addendum	$= \frac{0.8}{\text{D.P.}}$	$= 0.2546 \times$ C.P.
2. Minimum dedendum	$= \frac{1}{\text{D.P.}}$	$= 0.3183 \times$ C.P.
3. Working depth	$= \frac{1.6}{\text{D.P.}}$	$= 0.5092 \times$ C.P.
4. Minimum total depth	$= \frac{1.8}{\text{D.P.}}$	$= 0.5729 \times$ C.P.
5. Pitch diameter	$= \frac{\text{N.}}{\text{D.P.}}$	$= 0.3183 \times$ N. $\times$ C.P.
6. Outside diameter	$= \frac{\text{N.} + 1.6}{\text{D.P.}}$	= P.D. + (2 addendums)

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[1] N = number of teeth. D.P. = diametral pitch. P.D. = pitch diameter. C.P. = circular pitch. The term diametral pitch is used up to 1 D.P. inclusive and the term "circular pitch" is used for 3 in. C.P. and over.

NOTE.—A minimum root clearance of 0.2 in./diametral pitch is recommended for new cutters and gears. There is correct tooth action, however, between gears cut to this standard system and those cut to the Nuttall system, the only dimension affected being the clearance. Where the proposed gear tooth meshes with a Nuttall gear space there is a clearance of 0.1425 in./diametral pitch, and where the Nuttall tooth runs with the proposed gear space there is a clearance of 0.2146 in./diametral pitch.

CONSTANTS FOR DETERMINING CHORDAL PITCH AND RADIUS OF SPUR GEARS

P = chordal pitch of teeth.
R = radius of pitch circle.
N = number of teeth.
C = constant (see table below).

$$\text{Chordal pitch} = \frac{\text{radius of pitch circle}}{\text{constant for number of teeth}}.$$

Radius of pitch circle = constant × chordal pitch.

$$\text{Constant for any number of teeth} = \frac{\text{radius of pitch circle}}{\text{chordal pitch of teeth}}.$$

EXAMPLES.—1. What is radius of pitch circle of a gear having 45 teeth, 1¾ inch pitch? Follow 40 in the table of constants to column 5 (making 45 teeth), and find 7.168. Multiply by pitch, 1¾ inch, and get 12.54 inches radius, or 25.08 pitch diameter.

2. What is the chordal pitch of a gear 32 inches pitch diameter, 67 teeth? Follow 60 in table to column 7 and find 10.668. Divide radius (½ of 32 = 16 inches) by constant. 16 ÷ 10.668 = 1.5 inch pitch.

3. What number of teeth has a gear of 1.5 inch chordal pitch and pitch diameter of 32 inches? Divide by 2 to get radius. Divide this by chordal pitch which will give constant: 16 ÷ 1.5 = 10.666. Look in table for this constant which will be found to represent 67 teeth.

TABLE 2.—CONSTANTS

N	0	1	2	3	4	5	6	7	8	9
0	0.000	0.000	0.500	0.577	0.707	0.851	1.000	1.152	1.307	1.462
10	1.618	1.774	1.932	2.089	2.247	2.405	2.563	2.721	2.879	3.038
20	3.196	3.355	3.513	3.672	3.831	3.989	4.148	4.307	4.465	4.624
30	4.783	4.942	5.101	5.260	5.419	5.578	.737	5.896	6.055	6.214
40	6.373	6.532	6.691	6.850	7.009	7.168	7.327	7.486	7.645	7.804
50	7.963	8.122	8.281	8.440	8.599	8.758	8.918	9.077	9.236	9.395
60	9.554	9.713	9.872	10.031	10.190	10.349	10.508	10.668	10.827	10.986
70	11.145	11.304	11.463	11.622	11.781	11.940	12.099	12.258	12.418	12.577
80	12.736	12.895	13.054	13.213	13.372	13.531	1 .690	13.849	14.008	14.168
90	14.327	14.486	14.645	14.804	14.963	15.123	15.282	15.441	15.600	15.759
100	15.918	16.077	16.236	16.395	16.554	16.713	16.873	17.032	17.191	17.350
110	17.509	17.668	17.828	17.987	18.146	18.305	18.464	18.624	18.783	18.942
120	19.101	19.260	19.419	19.579	19.738	19.897	20.056	20.215	20.375	20.534
130	20 693	20.852	21.011	21.170	21.330	21.489	21.648	21.807	21.966	22.126
140	22.285	22.444	22.603	22.762	22.921	23.081	23.240	23.399	23.558	23.717
150	23.877	24.036	24.195	24.354	24.513	24.672	24.832	24.991	25.150	25.309
160	25.468	25.627	25.787	25.946	26.105	26.264	26.423	26.583	26.742	26.901
170	27.060	27.219	27.378	27.538	27.697	27.856	28.015	28.174	28.334	28.493
180	28.652	28.811	28.970	29.129	29.289	29.448	29.607	29.766	29.925	30.085
190	30.242	30.403	30.562	30.721	30.880	31.040	31.199	31.358	31.517	31.676
200	31.830	31.989	32.148	32.307	32.446	32.625	32.785	32.944	33.103	33.262
210	33.427	33.586	33.746	33.905	34.064	34.223	34.382	34.542	34.701	34.860
220	35.019	35.178	35.337	35.497	35.656	35.815	35.974	36.133	36.293	36.452
230	36.611	36.770	36.929	37.088	37.248	37.407	37.566	37.725	37.884	38.044
240	38.203	38.362	38.521	38.680	38.839	38.999	39.158	39.317	39.476	39.635
250	39.795									

Gear Wheels

TABLE 3.—TOOTH PARTS
Diametral Pitch in First Column

Diametral Pitch	Circular Pitch	Thickness of Tooth on Pitch Line	Addendum and $\frac{1}{P}$	Working Depth of Tooth	Depth of Space below Pitch Line	Whole Depth of Tooth
P	*P'*	*t*	*s*	*D''*	*s+f*	*D''+f*
½	6.2832	3.1416	2.0000	4.0000	2.3142	4.3142
¾	4.1888	2.0944	1.3333	2.6666	1.5428	2.8761
1	3.1416	1.5708	1.0000	2.0000	1.1571	2.1571
1¼	2.5133	1.2566	.8000	1.6000	.9257	1.7257
1½	2.0944	1.0472	.6666	1.3333	.7714	1.4381
1¾	1.7952	.8976	.5714	1.1429	.6612	1.2326
2	1.5708	.7854	.5000	1.0000	.5785	1.0785
2¼	1.3963	.6981	.4444	.8888	.5143	.9587
2½	1.2566	.6283	.4000	.8000	.4628	.8628
2¾	1.1424	.5712	.3636	.7273	.4208	.7844
3	1.0472	.5236	.3333	.6666	.3857	.7190
3½	.8976	.4488	.2857	.5714	.3306	.6163
4	.7854	.3927	.2500	.5000	.2893	.5393
5	.6283	.3142	.2000	.4000	.2314	.4314
6	.5236	.2618	.1666	.3333	.1928	.3595
7	.4488	.2244	.1429	.2857	.1653	.3081
8	.3927	.1963	.1250	.2500	.1446	.2696
9	.3491	.1745	.1111	.2222	.1286	.2397
10	.3142	.1571	.1000	.2000	.1157	.2157
11	.2856	.1428	.0909	.1818	.1052	.1961
12	.2618	.1309	.0833	.1666	.0964	.1798
13	.2417	.1208	.0769	.1538	.0890	.1659
14	.2244	.1122	.0714	.1429	.0826	.1541

NOTE.—To obtain the size of any part of a diametral pitch not given in the table, divide the corresponding part of 1 diametral pitch by the pitch required.

As it is natural to think of gear pitches as the distance between teeth, the same as threads, it is well to fix in the mind the approximate center distances of the pitches most in use. Or it is easy to remember that, if the diametral pitch be divided by 3⅐, we have the teeth per inch on the pitch line. By this method we easily see that in a 10 diametral pitch gear, there are approximately 3 teeth per inch, but in a 22 diametral pitch, there will be just 7 teeth to the inch.

TABLE 3.—TOOTH PARTS—*Continued*

Diametral Pitch	Circular Pitch	Thickness of Tooth on Pitch Line	Addendum and $\frac{1}{P}$	Working Depth of Tooth	Depth of Space below Pitch Line	Whole Depth of Tooth
P	P'	t	s	D''	$s+f$	$D''+f$
15	.2094	.1047	.0666	.1333	.0771	.1438
16	.1963	.0982	.0625	.1250	.0723	.1348
17	.1848	.0924	.0588	.1176	.0681	.1269
18	.1745	.0873	.0555	.1111	.0643	.1198
19	.1653	.0827	.0526	.1053	.0609	.1135
20	.1571	.0785	.0500	.1000	.0579	.1079
22	.1428	.0714	.0455	.0909	.0526	.0980
24	.1309	.0654	.0417	.0833	.0482	.0898
26	.1208	.0604	.0385	.0769	.0445	.0829
28	.1122	.0561	.0357	.0714	.0413	.0770
30	.1047	.0524	.0333	.0666	.0386	.0719
32	.0982	.0491	.0312	.0625	.0362	.0674
34	.0924	.0462	.0294	.0588	.0340	.0634
36	.0873	.0436	.0278	.0555	.0321	.0599
38	.0827	.0413	.0263	.0526	.0304	.0568
40	.0785	.0393	.0250	.0500	.0289	.0539
42	.0748	.0374	.0238	.0476	.0275	.0514
44	.0714	.0357	.0227	.0455	.0263	.0490
46	.0683	0341	.0217	.0435	.0252	.0469
48	.0654	0327	.0208	.0417	.0241	.0449
50	.0628	.0314	.0200	.0400	.0231	.0431
56	.0561	.0280	.0178	.0357	.0207	.0385
60	.0524	.0262	.0166	.0333	.0193	.0360

NOTE.—To obtain the size of any part of a diametral pitch not given in the table, divide the corresponding part of 1 diametral pitch by the pitch required.

As it is natural to think of gear pitches as the distance between teeth, the same as threads, it is well to fix in the mind the approximate center distances of the pitches most in use. Or it is easy to remember that if the diametral pitch be divided by 3$\frac{1}{7}$ we have the teeth per inch on the pitch line. By this method we easily see that in a 10-diametral-pitch gear there are approximately 3 teeth per inch while in a 22 diametral pitch there will be just 7 teeth to the inch.

TABLE 4.—TOOTH PARTS
Circular Pitch in First Column

Circular Pitch	Threads or Teeth per Inch Linear	Diametral Pitch	Thickness of Tooth on Pitch Line	Addendum and Module	Working Depth of Tooth	Depth of Space below Pitch Line	Whole Depth of Tooth	Width of Thread-Tool at End	Width of Thread at Top
P'	$\frac{1''}{P'}$	P	t	s	D''	$s+f$	$D''+f$	$P' \times .31$	$P' \times .335$
2	$\frac{1}{2}$	1.5708	1.0000	.6366	1.2732	.7366	1.3732	.6200	.6700
$1\frac{7}{8}$	$\frac{8}{15}$	1.6755	.9375	.5968	1.1937	.6906	1.2874	.5813	.6281
$1\frac{3}{4}$	$\frac{4}{7}$	1.7952	.8750	.5570	1.1141	.6445	1.2016	.5425	.5863
$1\frac{5}{8}$	$\frac{8}{13}$	1.9333	.8125	.5173	1.0345	.5985	1.1158	.5038	.5444
$1\frac{1}{2}$	$\frac{2}{3}$	2.0944	.7500	.4775	.9549	.5525	1.0299	.4650	.5025
$1\frac{7}{16}$	$\frac{16}{23}$	2.1855	.7187	.4576	.9151	.5294	.9870	.4456	.4816
$1\frac{3}{8}$	$\frac{8}{11}$	2.2848	.6875	.4377	.8754	.5064	.9441	.4262	.4606
$1\frac{1}{3}$	$\frac{3}{4}$	2.3562	.6666	.4244	.8488	.4910	.9154	.4133	.4466
$1\frac{5}{16}$	$\frac{16}{21}$	2.3936	.6562	.4178	.8356	.4834	.9012	.4069	.4397
$1\frac{1}{4}$	$\frac{4}{5}$	2.5133	.6250	.3979	.7958	.4604	.8583	.3875	.4188
$1\frac{3}{16}$	$\frac{16}{19}$	2.6456	.5937	.3780	.7560	.4374	.8156	.3681	.3978
$1\frac{1}{8}$	$\frac{8}{9}$	2.7925	.5625	.3581	.7162	.4143	.7724	.3488	.3769
$1\frac{1}{16}$	$\frac{16}{17}$	2.9568	.5312	.3382	.6764	.3913	.7295	.3294	.3559
1	1	3.1416	.5000	.3183	.6366	.3683	.6866	.3100	.3350
$\frac{15}{16}$	$1\frac{1}{15}$	3.3510	.4687	.2984	.5968	.3453	.6437	.2906	.3141
$\frac{7}{8}$	$1\frac{1}{7}$	3.5904	.4375	.2785	.5570	.3223	.6007	.2713	.2931
$\frac{13}{16}$	$1\frac{3}{13}$	3.8666	.4062	.2586	.5173	.2993	.5579	.2519	.2722
$\frac{4}{5}$	$1\frac{1}{4}$	3.9270	.4000	.2546	.5092	.2946	.5492	.2480	.2680
$\frac{3}{4}$	$1\frac{1}{3}$	4.1888	.3750	.2387	.4775	.2762	.5150	.2325	.2513
$\frac{11}{16}$	$1\frac{5}{11}$	4.5696	.3437	.2189	.4377	.2532	.4720	.2131	.2303
$\frac{2}{3}$	$1\frac{1}{2}$	4.7124	.3333	.2122	.4244	.2455	.4577	.2066	.2233
$\frac{5}{8}$	$1\frac{3}{5}$	5.0265	.3125	.1989	.3979	.2301	.4291	.1938	.2094
$\frac{3}{5}$	$1\frac{2}{3}$	5.2360	.3000	.1910	.3820	.2210	.4120	.1860	.2010
$\frac{4}{7}$	$1\frac{3}{4}$	5.4978	.2857	.1819	.3638	.2105	.3923	.1771	.1914
$\frac{9}{16}$	$1\frac{7}{9}$	5.5851	.2812	.1790	.3581	.2071	.3862	.1744	.1884

NOTE.—To obtain the size of any part of a circular pitch not given in the table, multiply the corresponding part of 1 second pitch by the pitch required.

As an example take a gear having 21 diametral pitch to find the various tooth parts. Take 1 diametral pitch and divide 3.1416 by 21 to find the corresponding circular pitch, which is 0.14951. The tooth thickness is 1.5708 ÷ 21 = 0.0748; the addendum is 1.0 ÷ 21 = 0.04761: the working depth is 2.0 ÷ 21. = 0.09522; the depth

TABLE 4.—TOOTH PARTS—*Continued*

Circular Pitch	Threads or Teeth per Inch Linear	Diametral Pitch	Thickness of Tooth on Pitch Line	Addendum and Module	Working Depth of Tooth	Depth of Space below Pitch Line	Whole Depth of Tooth	Width of Thread-Tool at End	Width of Thread at Top
P'	$\frac{1''}{P'}$	P	t	s	D''	$s+f$	$D''+f$	$P'\times.31$	$P'\times.335$
$\frac{1}{2}$	2	6.2832	.2500	.1592	.3183	.1842	.3433	.1550	.1675
$\frac{4}{9}$	$2\frac{1}{4}$	7.0685	.2222	.1415	.2830	.1637	.3052	.1378	.1489
$\frac{7}{16}$	$2\frac{2}{7}$	7.1808	.2187	.1393	.2785	.1611	.3003	.1356	.1466
$\frac{3}{7}$	$2\frac{1}{3}$	7.3304	.2143	.1364	.2728	.1578	.2942	.1328	.1436
$\frac{2}{5}$	$2\frac{1}{2}$	7.8540	.2000	.1273	.2546	.1473	.2746	.1240	.1340
$\frac{3}{8}$	$2\frac{2}{3}$	8.3776	.1875	.1194	.2387	.1381	.2575	.1163	.1256
$\frac{4}{11}$	$2\frac{3}{4}$	8.6394	.1818	.1158	.2316	.1340	.2498	.1127	.1218
$\frac{1}{3}$	3	9.4248	.1666	.1061	.2122	.1228	.2289	.1033	.1117
$\frac{5}{16}$	$3\frac{1}{5}$	10.0531	.1562	.0995	.1989	.1151	.2146	.0969	.1047
$\frac{3}{10}$	$3\frac{1}{3}$	10.4719	.1500	.0955	.1910	.1105	.2060	.0930	.1005
$\frac{2}{7}$	$3\frac{1}{2}$	10.9956	.1429	.0909	.1819	.1052	.1962	.0886	.0957
$\frac{1}{4}$	4	12.5664	.1250	.0796	.1591	.0921	.1716	.0775	.0838
$\frac{2}{9}$	$4\frac{1}{2}$	14.1372	.1111	.0707	.1415	.0818	.1526	.0689	.0744
$\frac{1}{5}$	5	15.7080	.1000	.0637	.1273	.0737	.1373	.0620	.0670
$\frac{3}{16}$	$5\frac{1}{3}$	16.7552	.0937	.0597	.1194	.0690	.1287	.0581	.0628
$\frac{2}{11}$	$5\frac{1}{2}$	17.2788	.0909	.0579	.1158	.0670	.1249	.0564	.0609
$\frac{1}{6}$	6	18.8496	.0833	.0531	.1061	.0614	.1144	.0517	.0558
$\frac{2}{13}$	$6\frac{1}{2}$	20.4203	.0769	.0489	.0978	.0566	.1055	.0477	.0515
$\frac{1}{7}$	7	21.9911	.0714	.0455	.0910	.0526	.0981	.0443	.0479
$\frac{2}{15}$	$7\frac{1}{2}$	23.5619	.0666	.0425	.0850	.0492	.0917	.0414	.0446
$\frac{1}{8}$	8	25.1327	.0625	.0398	.0796	.0460	.0858	.0388	.0419
$\frac{1}{9}$	9	28.2743	.0555	.0354	.0707	.0409	.0763	.0344	.0372
$\frac{1}{10}$	10	31.4159	.0500	.0318	.0637	.0368	.0687	.0310	.0335
$\frac{1}{16}$	16	50.2655	.0312	.0199	.0398	.0230	.0429	.0194	.0209
$\frac{1}{20}$	20	62.8318	.0250	.0159	.0318	.0184	.0343	.0155	.0167

NOTE.—To obtain the size of any part of a circular pitch not given in the table, multiply the corresponding part of 1 second pitch by the pitch required.

below pitch line is 1.1571 ÷ 21 = 0.0551 and the whole depth is 2.1571 ÷ 21 = 0.1027 inch. These could also have been obtained by splitting the difference between the figures for 20 and 22 pitch. The same can be done for circular pitch except that we multiply instead of divide.

LAYING OUT SPUR-GEAR BLANKS

Decide upon the size wanted, remembering that 12-pitch teeth are $\frac{2}{12}$ deep, and 8-pitch—as in Fig. 8—$\frac{2}{8}$ deep, etc. Should it be 8 pitch, as shown, draw a circle measuring as many eighths of an inch in diameter as there are to be teeth in the gear. This circle is called the "pitch line." Then with a radius $\frac{1}{8}$ inch larger, draw another circle from the same center, which will give the outside diameter of the gear, or $\frac{2}{8}$ larger than the pitch circle. Thus we have for the diameter of an 8-pitch gear of 24 teeth, $\frac{26}{8}$. Should there be 16 teeth, as in the small spur gear shown, the outside diameter would be $\frac{18}{8}$, the number of teeth being always two less than there are eighths—*when it is* 8 *pitch*—in the outside diameter.

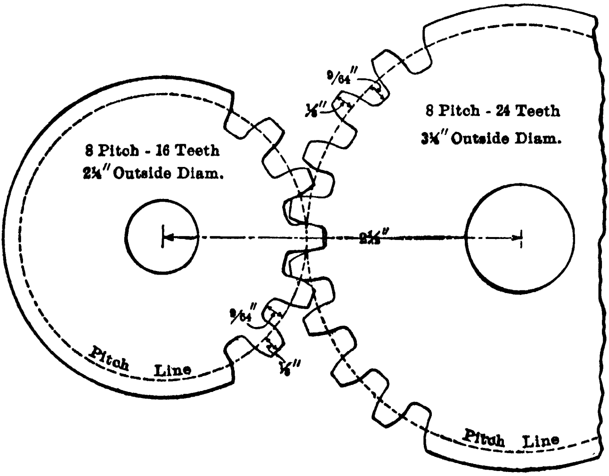


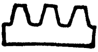
FIG. 8.—Laying Out a Pair of Gears

The distance from the pitch line to the bottom of the teeth is the same as to the top, except the clearance, which varies from $\frac{1}{8}$ of the pitch to $\frac{1}{10}$ of the thickness of the tooth at the pitch line. This latter is used by Brown and Sharpe and many others, but the clearance being provided for in the cutters, the two gears would be laid out to mesh together just $\frac{2}{8}$.

These rules apply to all pitches, so that the outside diameter of a 5-pitch gear with 24 teeth would be $\frac{26}{5}$; if a 3-pitch gear with 40 teeth, it would be $\frac{42}{3}$. Again, if a blank be $4\frac{1}{6}$ ($\frac{25}{6}$) in diameter and cut 6 pitch, it should contain 23 teeth.

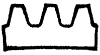
Actual Size of Diametral Pitches

It is not always easy to judge or imagine just how large a given pitch is when measured by the diametral system. To make it



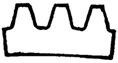
20 P.

0.1571 C.P.
1.270 M.M.



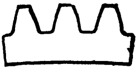
18 P.

0.1745 C.P.
1.411 M.M.



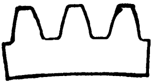
16 P.

0.1963 C.P.
1.587 M.M.



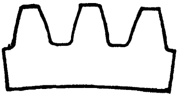
14 P.

0.2244 C.P.
1.814 M.M.



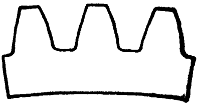
12 P.

0.2618 C.P.
2.116 M.M.



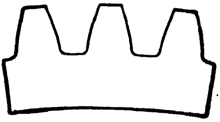
10 P.

0.3142 C.P.
2.540 M.M.



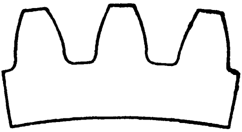
9 P.

0.3491 C.P.
2.822 M.M.



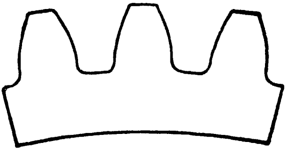
8 P.

0.3927 C.P.
3.175 M.M.



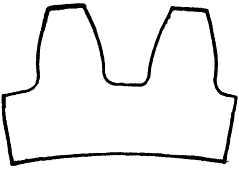
7 P.

0.4488 C.P.
3.628 M.M.



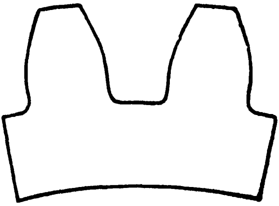
6 P

0.5236 C.P.
4.233 M.M.



5 P.

0.6283 C.P.
5.080 M.M.



4 P.

0.7854 C.P.
6.350 M.M.

C.P. = Circular Pitch. M.M. = m/m Module.

easy to see just what any pitch looks like, the actual sizes of twelve diametral pitches are given on the preceding page, ranging from 20 to 4 teeth per inch of diameter on the pitch line, so that a good idea of the size of any of these teeth can be had at a glance.

PRESSURE ANGLES

The pressure angle of gear teeth means the angle at which one tooth presses against the other and can best be shown by the pinion and rack, Figs. 9 and 10.

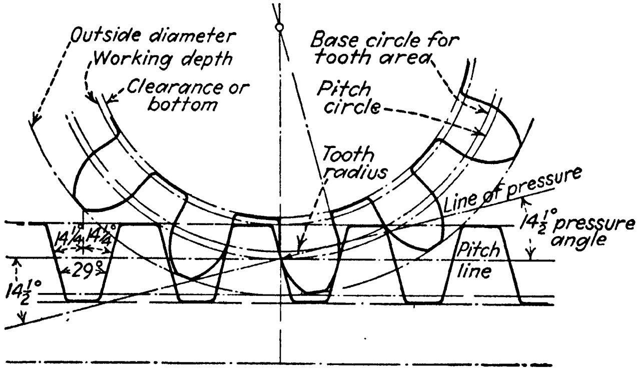


FIG. 9.—Standard Tooth

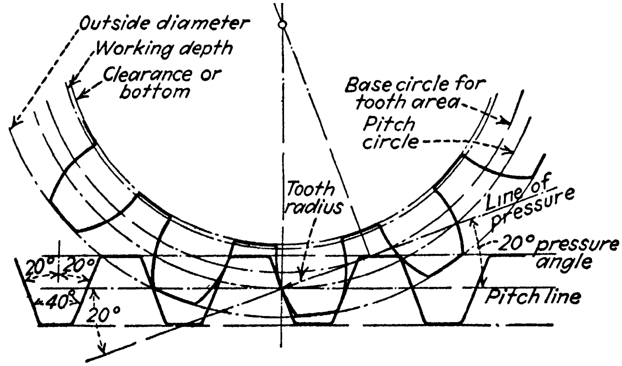


FIG. 10.—Stubbed Tooth

The standard tooth has a 14½-degree pressure angle. The sides of an involute rack tooth are straight, and at the pressure angle from the perpendicular, draw the line of pressure at 14½ degrees from the pitch line.

The difference between the 14½- and 20-degree pressure angles can be seen by comparing Figs. 9 and 10. Not only is the tooth shorter, but the base is broader.

STUB-TOOTH GEARS

Any tooth shorter than the regular standard length is called a "stub" tooth, but like the bastard thread there have been many kinds. In 1899, the Fellows Gear Shaper Company introduced a short tooth with a 20-degree pressure angle instead of the usual 14½-degree. This gives a broader flank to the tooth and makes a stronger gear, especially for small pinions where strength is needed. While the Fellows tooth is shorter than the standard tooth, there is no fixed relation between them, as, on account of the tooth depth graduations of the gear shaper, it was thought best to give the new tooth depth in the same scale which is shown in table on this page. This means that if the pitch is 4, it has the depth of a 5-pitch standard tooth divided as shown. The clearance is one-quarter the addendum or dedendum.

TABLE 5.—GEAR-TOOTH PARTS (20-DEGREE PRESSURE ANGLE, STUB-TOOTH FORM)
The Fellows Gear Shaper Company Standard

Diametral Pitch	Dimensions in Inches				
	Thickness on Pitch Line	Addendum	Dedendum Plus Clearance	Whole Depth of Tooth	Double Depth of Tooth
3/4	0.5236	0.2500	0.3125	0.5625	1.1250
4/5	0.3927	0.2000	0.2500	0.4500	0.9000
5/7	0.3142	0.1429	0.1786	0.3215	0.6430
6/8	0.2618	0.1250	0.1562	0.2812	0.5625
7/9	0.2244	0.1111	0.1389	0.2500	0.5000
8/10	0.1963	0.1000	0.1250	0.2250	0.4500
9/11	0.1745	0.0909	0.1136	0.2045	0.4090
10/12	0.1571	0.0833	0.1042	0.1875	0.3750
12/14	0.1309	0.0714	0.0893	0.1607	0.3214
13/16	0.1208	0.0625	0.0781	0.1406	0.2812
14/18	0.1122	0.0555	0.0694	0.1250	0.2500
15/20	0.1047	0.0500	0.0625	0.1125	0.2250
16/21	0.0982	0.0476	0.0595	0.1071	0.2142
17/22	0.0924	0.0454	0.0568	0.1023	0.2046
18/24	0.0873	0.0417	0.0521	0.0937	0.1875
19/25	0.0827	0.0400	0.0500	0.0900	0.1800
20/26	0.0785	0.0385	0.0481	0.0865	0.1731
21/28	0.0748	0.0357	0.0446	0.0803	0.1607
22/29	0.0714	0.0345	0.0431	0.0776	0.1552
23/30	0.0683	0.0330	0.0412	0.0742	0.1485
24/32	0.0654	0.0312	0.0391	0.0703	0.1406

TABLE 6.—OUTSIDE DIAMETERS OF STUB-TOOTH GEARS

$\text{P.D.} = \dfrac{\text{no. teeth}}{\text{numerator pitch}}$ $\text{addendum} = \dfrac{1}{\text{denominator pitch}}$ $\text{clear} = \dfrac{\text{addendum}}{4}$

$\text{O.D.} = \text{P.D.} + \left(2 \times \dfrac{1}{\text{denominator pitch}}\right)$ $\text{dedendum} = \dfrac{1}{\text{denominator pitch}}.$

Pitch	$\frac{3}{4}$	$\frac{4}{5}$	$\frac{5}{7}$	$\frac{6}{8}$	$\frac{7}{9}$	$\frac{8}{10}$	$\frac{9}{11}$	$\frac{10}{12}$	$\frac{12}{14}$	$\frac{16}{21}$
Number of Teeth										
14	5.167	3.900	3.086	2.583	2.222	1.950	1.738	1.567	1.310	.970
15	5.500	4.150	3.286	2.750	2.365	2.075	1.849	1.667	1.393	1.033
16	5.833	4.400	3.486	2.917	2.508	2.200	1.960	1.767	1.476	1.095
17	6.167	4.650	3.686	3.083	2.651	2.325	2.071	1.867	1.560	1.158
18	6.500	4.900	3.886	3.250	2.794	2.450	2.182	1.967	1.643	1.220
19	6.833	5.150	4.086	3.417	2.937	2.575	2.292	2.067	1.726	1.283
20	7.167	5.400	4.286	3.583	3.080	2.700	2.404	2.167	1.809	1.345
22	7.833	5.900	4.686	3.917	3.365	2.950	2.626	2.367	1.976	1.470
24	8.500	6.400	5.086	4.250	3.651	3.200	2.849	2.567	2.143	1.595
26	9.167	6.900	5.486	4.583	3.937	3.450	3.071	2.767	2.310	1.720
28	9.833	7.400	5.886	4.917	4.222	3.700	3.293	2.967	2.476	1.845
30	10.500	7.900	6.286	5.250	4.508	3.950	3.515	3.167	2.643	1.970
32	11.167	8.400	6.686	5.583	4.794	4.200	3.738	3.367	2.809	2.095
34	11.833	8.900	7.086	5.917	5.080	4.450	3.960	3.567	2.976	2.220
36	12.500	9.400	7.486	6.250	5.365	4.700	4.182	3.767	3.143	2.345
38	13.167	9.900	7.886	6.583	5.651	4.950	4.404	3.967	3.310	2.470
40	13.833	10.400	8.286	6.917	5.937	5.200	4.626	4.167	3.476	2.595
42	14.500	10.900	8.686	7.250	6.222	5.450	4.849	4.367	3.643	2.720
44	15.167	11.400	9.086	7.583	6.508	5.700	5.071	4.567	3.809	2.845
46	15.833	11.900	9.486	7.917	6.794	5.950	5.293	4.767	3.976	2.970
48	16.500	12.400	9.886	8.250	7.080	6.200	5.515	4.967	4.143	3.095
50	17.167	12.900	10.286	8.583	7.365	6.450	5.738	5.167	4.310	3.220
52	17.833	13.400	10.686	8.917	7.651	6.700	5.960	5.367	4.476	3.345
54	18.500	13.900	11.086	9.250	7.937	6.950	6.182	5.567	4.643	3.470
56	19.167	14.400	11.486	9.583	8.222	7.200	6.404	5.767	4.809	3.595
58	19.833	14.900	11.886	9.917	8.508	7.450	6.626	5.967	4.976	3.720
60	20.500	15.400	12.286	10.250	8.794	7.700	6.849	6.167	5.143	3.845
62	21.167	15.900	12.686	10.583	9.080	7.950	7.071	6.367	5.310	3.970
64	21.833	16.400	13.086	10.917	9.365	8.200	7.293	6.567	5.476	4.095
66	22.500	16.900	13.486	11.250	9.651	8.450	7.515	6.767	5.643	4.220
68	23.167	17.400	13.886	11.583	9.937	8.700	7.738	6.967	5.809	4.345
70	23.833	17.900	14.286	11.917	10.222	8.950	7.960	7.167	5.976	4.470

INTERFERENCE IN INVOLUTE GEARING

Interference between the teeth of involute gears is to be avoided, and in laying out a gear train, it is convenient to know the smallest permissible number of teeth in the driving pinion which can be used and at the same time avoid interference.

As the straight-sided rack is the basis of the involute system, interference between teeth is worked out on the basis of the rack.

A formula which can be used for this purpose is as follows in which N equals the smallest number of teeth in the pinion and the constant equals the addendum length:

$$N = 2 \times \frac{\tan^2 \text{ of pressure angle} + \text{constant}}{\tan^2 \text{ of pressure angle}}.$$

The accompanying table contains a compilation of values based on this formula and covering three different addendum lengths: The so-called "standard" or 1-inch addendum that is based on 1 diametral pitch; the stub tooth, which, on 1 diametral pitch, is $\frac{8}{10}$-inch or 0.800; and ⅞-inch addendum or 0.875 for 1 diametral pitch. The pressure angles range from 14½ to 30 degrees, inclusive.

It is interesting to note that 32 teeth is the smallest number with a 14½-degree pressure angle and a full length tooth which will avoid interference with a standard unmodified rack of the same tooth proportions; whereas, by shortening the addendum to $\frac{8}{10}$ inch, 26 teeth can be used with a 14½-degree pressure angle.

The formula given above can, of course, be used to obtain the smallest permissible number of teeth with any addendum length by inserting the value over the addendum length where the constant appears in the formula.

TABLE 7.—SMALLEST PERMISSIBLE NUMBER OF TEETH IN PINION TO AVOID INTERFERENCE WITH RACK OF SAME PROPORTIONS
Addendum Lengths Based on 1 Diametral Pitch

Pressure Angle	Smallest Number of Teeth in Pinion		
	1 In. Addendum	⅞ In. Addendum	$\frac{8}{10}$ In. Addendum
14° 30′	32	28	26
15°	30	26	24
17°	24	21	19
20°	18	15	14
22° 30′	14	12	11
24°	12	11	10
27° 30′	10	9	8
30°	9	7	7

LONG AND SHORT ADDENDUM TEETH

A careful analysis of the action of involute gears indicates that the best tooth action will result when the addenda on the gear and pinion are made in proportion in length to the ratio between the number of teeth in mesh.

Using a long addendum pinion and short addendum gear reduces the angle of approach and increases the angle of recession. The

Pitch Diameters of Standard Gears

The accompanying tables require little explanation, being simply given to save time in laying out gear trains. Having the diametral pitch and the number of teeth, the pitch diameter is easily found from the tables. They also show the corresponding circular pitch, designated by C. P. Diameters of larger gears are found by multiplication.

Having the pitch diameter, the outside diameter can easily be found by adding two parts of the pitch of standard gears. The outside diameter of any gear with standard teeth is the same as the pitch diameter of two more teeth.

TABLE 8.—PITCH DIAMETER OF GEARS WHEN DIAMETRAL PITCH AND THE NUMBER OF TEETH ARE KNOWN

D.P. C.P.	1.5 2.094	2 1.571	2.5 1.257	3 1.047	4 0.785	5 0.628	6 0.524	8 0.393	10 0.3142	12 0.2618	14 0.2244	16 0.1963	20 0.1571
No. T													
15.......	10.000	7.50	6.00	5.000	3.75	3.00	2.500	1.875	1.5	1.250	1.071	0.937	0.75
16.......	10.666	8.00	6.40	5.333	4.00	3.20	2.666	2.000	1.6	1.333	1.142	1.000	0.80
17.......	11.333	8.50	6.80	5.666	4.25	3.40	2.833	2.125	1.7	1.416	1.214	1.062	0.85
18.......	12.000	9.00	7.20	6.000	4.50	3.60	3.000	2.250	1.8	1.500	1.285	1.125	0.90
19.......	12.666	9.50	7.60	6.333	4.75	3.80	3.166	2.375	1.9	1.583	1.357	1.187	0.95
20.......	13.333	10.00	8.00	6.666	5.00	4.00	3.333	2.500	2.0	1.666	1.428	1.250	1.00
21.......	14.000	10.50	8.40	7.000	5.25	4.20	3.500	2.625	2.1	1.750	1.500	1.312	1.05
22.......	14.666	11.00	8.80	7.333	5.50	4.40	3.666	2.750	2.2	1.833	1.571	1.375	1.10
23.......	15.333	11.50	9.20	7.666	5.75	4.60	3.833	2.875	2.3	1.916	1.642	1.437	1.15
24.......	16.000	12.00	9.60	8.000	6.00	4.80	4.000	3.000	2.4	2.000	1.714	1.500	1.20
25.......	16.666	12.50	10.00	8.333	6.25	5.00	4.166	3.125	2.5	2.083	1.785	1.562	1.25
26.......	17.333	13.00	10.40	8.666	6.50	5.20	4.333	3.250	2.6	2.167	1.857	1.625	1.30
27.......	18.000	13.50	10.80	9.000	6.75	5.40	4.500	3.375	2.7	2.250	1.928	1.687	1.35
28.......	18.666	14.00	11.20	9.333	7.00	5.60	4.666	3.500	2.8	2.333	2.000	1.750	1.40
29.......	19.333	14.50	11.60	9.666	7.25	5.80	4.833	3.625	2.9	2.416	2.071	1.812	1.45
30.......	20.000	15.00	12.00	10.000	7.50	6.00	5.000	3.750	3.0	2.500	2.142	1.875	1.50
31.......	20.666	15.50	12.40	10.333	7.75	6.20	5.166	3.875	3.1	2.583	2.214	1.937	1.55
32.......	21.333	16.00	12.80	10.666	8.00	6.40	5.333	4.000	3.2	2.666	2.285	2.000	1.60
33.......	22.000	16.50	13.20	11.000	8.25	6.60	5.500	4.125	3.3	2.750	2.357	2.062	1.65
34.......	22.666	17.00	13.60	11.333	8.50	6.80	5.666	4.250	3.4	2.833	2.428	2.125	1.70
35.......	23.333	17.50	14.00	11.666	8.75	7.00	5.833	4.375	3.5	2.916	2.500	2.187	1.75

D.P. C.P.	1.5 2.094	2 1.571	2.5 1.257	3 1.047	4 0.785	5 0.628	6 0.524	8 0.393	10 0.3142	12 0.2618	14 0.2244	16 0.1963	20 0.1571
No. T													
36.......	24.000	18.00	14.40	12.000	9.00	7.20	6.000	4.500	3.6	3.000	2.571	2.250	1.80
37.......	24.666	18.50	14.80	12.333	9.25	7.40	6.166	4.625	3.7	3.083	2.642	2.312	1.85
38.......	25.333	19.00	15.20	12.666	9.50	7.60	6.333	4.750	3.8	3.167	2.714	2.375	1.90
39.......	26.000	19.50	15.60	13.000	9.75	7.80	6.500	4.875	3.9	3.250	2.785	2.437	1.95
40.......	26.666	20.00	16.00	13.333	10.00	8.00	6.666	5.000	4.0	3.333	2.857	2.500	2.00
41.......	27.333	20.50	16.40	13.666	10.25	8.20	6.833	5.125	4.1	3.416	2.928	2.562	2.05
42.......	28.000	21.00	16.80	14.000	10.50	8.40	7.000	5.250	4.2	3.500	3.000	2.625	2.10
43.......	28.666	21.50	17.20	14.333	10.75	8.60	7.166	5.375	4.3	3.583	3.071	2.687	2.15
44.......	29.333	22.00	17.60	14.666	11.00	8.80	7.333	5.500	4.4	3.666	3.142	2.750	2.20
45.......	30.000	22.50	18.00	15.000	11.25	9.00	7.500	5.625	4.5	3.750	3.214	2.812	2.25
46.......	30.666	23.00	18.40	15.333	11.50	9.20	7.666	5.750	4.6	3.833	3.285	2.875	2.30
47.......	31.333	23.50	18.80	15.666	11.75	9.40	7.833	5.875	4.7	3.916	3.357	2.937	2.35
48.......	32.000	24.00	19.20	16.000	12.00	9.60	8.000	6.000	4.8	4.000	3.428	3.000	2.40
49.......	32.666	24.50	19.60	16.333	12.25	9.80	8.166	6.125	4.9	4.083	3.500	3.062	2.45
50.......	33.333	25.00	20.00	16.666	12.50	10.00	8.333	6.250	5.0	4.167	3.571	3.125	2.50
51.......	34.000	25.50	20.40	17.000	12.75	10.20	8.500	6.375	5.1	4.250	3.642	3.187	2.55
52.......	34.666	26.00	20.80	17.333	13.00	10.40	8.666	6.500	5.2	4.333	3.714	3.250	2.60
53.......	35.333	26.50	21.20	17.666	13.25	10.60	8.833	6.625	5.3	4.416	3.785	3.312	2.65
54.......	36.000	27.00	21.60	18.000	13.50	10.80	9.000	6.750	5.4	4.500	3.857	3.375	2.70
55.......	36.666	27.50	22.00	18.333	13.75	11.00	9.166	6.875	5.5	4.583	3.928	3.437	2.75
56.......	37.333	28.00	22.40	18.666	14.00	11.20	9.333	7.000	5.6	4.666	4.000	3.500	2.80
57.......	38.000	28.50	22.80	19.000	14.25	11.40	9.500	7.125	5.7	4.750	4.071	3.562	2.85
58.......	38.666	29.00	23.20	19.333	14.50	11.60	9.666	7.250	5.8	4.833	4.142	3.625	2.90
59.......	39.333	29.50	23.60	19.666	14.75	11.80	9.833	7.375	5.9	4.916	4.214	3.687	2.95
60.......	40.000	30.00	24.00	20.000	15.00	12.00	10.000	7.500	6.0	5.000	4.285	3.750	3.00
61.......	40.666	30.50	24.40	20.333	15.25	12.20	10.166	7.625	6.1	5.083	4.357	3.812	3.05
62.......	41.333	31.00	24.80	20.666	15.50	12.40	10.333	7.750	6.2	5.167	4.428	3.875	3.10
63.......	42.000	31.50	25.20	21.000	15.75	12.60	10.500	7.875	6.3	5.250	4.500	3.937	3.15
64.......	42.666	32.00	25.60	21.333	16.00	12.80	10.666	8.000	6.4	5.333	4.571	4.000	3.20
65.......	43.333	32.50	26.00	21.666	16.25	13.00	10.833	8.125	6.5	5.416	4.642	4.062	3.25
66.......	44.000	33.00	26.40	22.000	16.50	13.20	11.000	8.250	6.6	5.500	4.714	4.125	3.30

action of gears so designed is smoother when the angle of recession is greater than the angle of approach. A pressure angle should also be selected which will avoid interference, and by reference to the preceding table, if we know the smallest number of teeth in the pinion, we can then select a pressure angle which will avoid interference.

To illustrate, assume that it is desired to figure the addenda of a 7-pitch gear and pinion having a tooth ratio of 33 to 18 teeth, respectively. Also assume that we will make the addenda $\frac{7}{8}$ inch based on 1 diametral pitch. For a 7-pitch gear, this would give an addendum length of 0.125 inch. The total addenda, therefore, on gear and pinion would be 0.250 inch. By referring back to Table 7, we would have to select a pressure angle of 20 degrees to avoid interference with a 15-tooth pinion. The ratio between the number of teeth is 33 over 18, or 1.8333:1. In other words, the length of the addendum on the pinion should be 1.833 times greater than that on the gear. The sum of the addenda on the gear and pinion is 0.250 inch. Therefore, the addenda of the gear will be 0.250 over 1.833 plus 1, or 0.0882 inch, and the addendum on the pinion will be 0.250 minus 0.0882 equals 0.1618 inch.

Table 8*a*.—Total Tooth Space Depth for Shaved Gears of Standard Tooth Proportions with Sixteen or More Teeth

Normal Pitch[1]	Formula for Obtaining Total Tooth Space Depth (D)
4	$D = \frac{2.25}{P}$
5 to 6	$D = \frac{2.25}{P} + 0.015$ inch
7 to 9	$D = \frac{2.25}{P} + 0.020$ inch
10 to 29	$D = \frac{2.45}{P}$
30 to 45	$D = \frac{2.45}{P}$
46 to 64	$D = \frac{2}{P} + 0.010$ inch
65 to 100	$D = \frac{2}{P} + 0.007$ inch

[1] In spur gears, the normal and diametral pitch are the same. For helical gears, where the pitch is a fraction, and for Fellows stub-tooth gears, use the denominator pitch as the divisor.

TABLE 8b.—20-DEGREE PRESSURE ANGLE INVOLUTE SPUR GEARS
(A.G.M.A. Tentative Standard for Fine Pitch Gears[1])

Enlarged Pinion					Standard Center Distance System Short Addendum Gear Dimensions			Enlarged Center Distance System. Standard Mating Gear
1	2	3	4	5	6	7	8	9
No. of Teeth, n	Outside Diam., D_0	Cir. Tooth Thickness at Std. Pitch Diam., t	Measurement over 1.92 Inch Diam. Wires, M	[2]Reduction in M to Thin Tooth 0.001	Decrease in Outside Diam. D_0	Cir. Tooth Thickness at Std. Pitch Diam., T $\pi - t$	Recommended Minimum No. of Teeth	Increase over Standard Center Distance
10	12.8302	1.8730	13.4408	0.0016	0.8302	1.2686	33	0.4151
11	13.7132	1.8304	14.2678	0.0017	0.7132	1.3112	30	0.3566
12	14.5963	1.7878	15.3428	0.0017	0.5963	1.3538	27	0.2982
13	15.4793	1.7452	16.1807	0.0018	0.4793	1.3964	25	0.2397
14	16.3623	1.7027	17.2233	0.0018	0.3623	1.4389	23	0.1812
15	17.2453	1.6601	18.0674	0.0019	0.2453	1.4815	21	0.1227
16	18.1284	1.6175	19.0851	0.0019	0.1284	1.5241	19	0.0642
17	19.0114	1.5749	19.9326	0.0020	0.0114	1.5667	18	0.0057

[1] Refer to A.G.M.A. Pamphlet 207.01, Feb., 1944. Copyright, 1944.

[2] These reductions are approximately correct for all diametral pitches. Do not divide by diametral pitch.

NOTE.—Dimensions required when using enlarged pinions.
Dimensions are in inches for 1 diametral pitch. For other pitches divide table values by diametral pitch.
These values are suitable only for 20-degree full depth involute gears. They cannot be used for other pressure angles.

Table 8c.—14½-Degree Pressure Angle Involute Spur Gears (Full Depth)

	Enlarged Pinion (Long Addendum)				Short Addendum Gear Mates Enlarged Pinion at Standard Center Distance			Enlarged Center Distance System Standard Mating Gear.
Number of Teeth n	Outside Diameter d_o	Circular Tooth Thickness at Standard Pitch Diameter, t	Measurement over 1.92 Diameter Wires, M	[1]Reduction in Measurement to Thin Tooth 0.001	Decrease in Outside Diameter D_o	Circular Tooth Thickness at Standard Pitch Diameter	Recommended Minimum Number of Teeth T	Increase over Standard Center Distance
10	13.3731	1 9259	13.6186	0.0017	1.3731	1.2157	54	0.6866
11	14.3104	1.9097	14.4966	0.0018	1.3104	1.2319	53	0.6552
12	15.2477	1.8935	15.6290	0.0018	1.2477	1.2481	52	0.6239
13	16.1850	1.8773	16.5211	0.0019	1.1850	1.2643	51	0.5925
14	17.1223	1.8611	17.6244	0.0019	1.1223	1.2805	50	0.5612
15	18.0597	1.8449	18.5260	0.0020	1.0597	1.2967	49	0.5299
16	18.9970	1.8286	19.6075	0.0020	0.9970	1.3130	48	0.4985
17	19.9343	1.8124	20.5156	0.0020	0 9343	1.3292	47	0.4672
18	20.8716	1.7962	21.5806	0.0021	0.8716	1.3454	46	0.4358
19	21.8089	1.7800	22.4934	0.0021	0.8089	1.3616	45	0.4045
20	22.7462	1.7638	23.5451	0.0022	0.7462	1.3778	44	0.3731
21	23.6835	1.7476	24.4611	0.0022	0.6835	1.3940	43	0.3418
22	24.6208	1.7314	25.5018	0.0023	0.6208	1.4102	42	0.3104
23	25.5881	1.7151	26.4201	0.0023	0.5581	1.4265	41	0.2791
24	26.4954	1.6989	27.4515	0.0023	0.4954	1.4427	40	0.2477
25	27.4328	1.6827	28.3718	0.0024	0.4328	1.4589	39	0.2164
26	28.3701	1.6665	29.3952	0.0024	0.3701	1.4751	38	0.1851
27	29.3074	1.6503	30.3168	0.0025	0.3074	1.4913	37	0.1537
28	30.2447	1.6341	31.3333	0.0025	0.2447	1.5075	36	0.1224
29	31.1820	1.6179	32.2558	0.0025	0.1820	1.5237	35	0.0910
30	32.1193	1.6017	33.2661	0.0026	0.1193	1.5399	34	0.0597
31	33.0566	1.5854	34.1889	0.0026	0.0566	1.5562	33	0.0283

[1] Approximately correct for all pitches. Do not divide by diametral pitch.
Dimensions for enlarged pinions (thirty-one and fewer teeth) and mating gears.
Refer to A. G. M. A. Standard. Values in inches at 1 diametral pitch.

MEASURING ENLARGED PINIONS WITH WIRES

Since the outside diameter and addendum have been increased, standard wires $\frac{1.728 \text{ inch}}{P}$ will come below the tops of the teeth of enlarged pinions, and a new series of wires is recommended which is $\frac{1.92 \text{ inch}}{P}$. This value results in sizes which in some cases are the same as some other standard external or internal sizes. Measurements over $\frac{1.92 \text{ inch}}{P}$ wires for 20-degree pressure angle pinions are given in Table 8*b*. The wire diameters are given in Table 8*d*. Pinions having eighteen or more teeth in the 20-degree pressure angle system are made standard.

TABLE 8*d*.—WIRE DIAMETERS FOR MEASURING ENLARGED PINIONS

P	G $\frac{1.92 \text{ Inch}}{P}$	P	G $\frac{1.92 \text{ Inch}}{P}$	P	G $\frac{1.92 \text{ Inch}}{P}$
2	0.960	11	0.17454	36	0.05333
2½	0.768	12	0.160[1]	40	0.048[1]
3	0.640	14	0.13714	48	0.040[1]
4	0.480[1]	16	0.120[1]	64	0.030[1]
5	0.384	18	0.10667	72	0.02667
6	0.320	20	0.096[1]	80	0.024[1]
7	0.27428	22	0.08727	100	0.0192
8	0.240[1]	24	0.080[1]	120	0.0160
9	0.21333	28	0.06857	160	0.0120
10	0.192[1]	32	0.060[1]	200	0.0096

[1] Standard external or internal gear wire sizes.

MEASURING REDUCED GEARS (SHORT ADDENDUM)

With the Fellows stub tooth gear the numerator represents the diametral pitch and should be used for calculating pitch diameter and circular pitch. The denominator is used in calculating addendum and dedendum. With a $\frac{7}{9}$ Fellows gear use $\frac{7}{9}$ for pitch and 9 for tooth depth. This means use a $7P$ wire for measuring.

TABLE 8e.—GEAR WIRE SIZES IN INCHES*

Diametral Pitch, P	For External Gears $G = \frac{1.728}{P}$ inch	For Internal Gears $G = \frac{1.44}{P}$ inch
2	0.864	0.720
2½	0.6912	0.576
3	0.576	0.480
4	0.432	0.360
6	0.288	0.240
7	0.24686	0.20571
8	0.216	0.180
9	0.192	0.160
10	0.1728	0.144
11	0.15709	0.13091
12	0.144	0.120
14	0.12343	0.10286
16	0.108	0.090
18	0.096	0.080
20	0.0864	0.072
22	0.07855	0.06545
24	0.072	0.060
28	0.06171	0.05143
32	0.054	0.045
36	0.048	0.040
40	0.0432	0.036
48	0.036	0.030
64	0.027	0.0225
72	0.024	0.020
80	0.0216	0.018

* These are Van Keuren wires which are 1¾ inches long and accurate within 0.000025 for size and soundness. Standardized at 1 pound pressure between flat contacts.

TABLE 8f.—SPECIAL SIZES OF GEAR WIRES

Size Range, in Inches	Size Range, in Inches
0.002–0.005	0.180–0.250
0.005–0.007	0.250–0.500
0.007–0.010	0.500–0.750
0.010–0.016	0.750–1.000
0.016–0.100	1.000–1.5708
0.100–0.180	

These special sizes are used in measuring helical gears and splines. They are made up in sets of two or in pairs.

TABLE 9.—TURNING AND CUTTING GEAR BLANKS FOR STANDARD-LENGTH TOOTH

Pitch	16	12	10	8
Depth of Tooth	.135	.180	.216	.270
No. of Teeth	Outside Diameter			
10	3/4	1	1 2/10	1 1/2
11	13/16	1 1/12	1 3/10	1 5/8
12	7/8	1 2/12	1 4/10	1 3/4
13	15/16	1 3/12	1 5/10	1 7/8
14	1	1 4/12	1 6/10	2
15	1 1/16	1 5/12	1 7/10	2 1/8
16	1 1/8	1 6/12	1 8/10	2 1/4
17	1 3/16	1 7/12	1 9/10	2 3/8
18	1 1/4	1 8/12	2	2 1/2
19	1 5/16	1 9/12	2 1/10	2 5/8
20	1 3/8	1 10/12	2 2/10	2 3/4
21	1 7/16	1 11/12	2 3/10	2 7/8
22	1 1/2	2	2 4/10	3
23	1 9/16	2 1/12	2 5/10	3 1/8
24	1 5/8	2 2/12	2 6/10	3 1/4
25	1 11/16	2 3/12	2 7/10	3 3/8
26	1 3/4	2 4/12	2 8/10	3 1/2
27	1 13/16	2 5/12	2 9/10	3 5/8
28	1 7/8	2 6/12	3	3 3/4
29	1 15/16	2 7/12	3 1/10	3 7/8
30	2	2 8/12	3 2/10	4
31	2 1/16	2 9/12	3 3/10	4 1/8
32	2 1/8	2 10/12	3 4/10	4 1/4
33	2 3/16	2 11/12	3 5/10	4 3/8
34	2 1/4	3	3 6/10	4 1/2
35	2 5/16	3 1/12	3 7/10	4 5/8
36	2 3/8	3 2/12	3 8/10	4 3/4
37	2 7/16	3 3/12	3 9/10	4 7/8
38	2 1/2	3 4/12	4	5
39	2 9/16	3 5/12	4 1/10	5 1/8
40	2 5/8	3 6/12	4 2/10	5 1/4
41	2 11/16	3 7/12	4 3/10	5 3/8
42	2 3/4	3 8/12	4 4/10	5 1/2
43	2 13/16	3 9/12	4 5/10	5 5/8
44	2 7/8	3 10/12	4 6/10	5 3/4
45	2 15/16	3 11/12	4 7/10	5 7/8
46	3	4	4 8/10	6
47	3 1/16	4 1/12	4 9/10	6 1/8
48	3 1/8	4 2/12	5	6 1/4
49	3 3/16	4 3/12	5 1/10	6 3/8
50	3 1/4	4 4/12	5 2/10	6 1/2
51	3 5/16	4 5/12	5 3/10	6 5/8
52	3 3/8	4 6/12	5 4/10	6 3/4
53	3 7/16	4 7/12	5 5/10	6 7/8
54	3 1/2	4 8/12	5 6/10	7
55	3 9/16	4 9/12	5 7/10	7 1/8
56	3 5/8	4 10/12	5 8/10	7 1/4
57	3 11/16	4 11/12	5 9/10	7 3/8
58	3 3/4	5	6	7 1/2
59	3 13/16	5 1/12	6 1/10	7 5/8
60	3 7/8	5 2/12	6 2/10	7 3/4
61	3 15/16	5 3/12	6 3/10	7 7/8
62	4	5 4/12	6 4/10	8
63	4 1/16	5 5/12	6 5/10	8 1/8
64	4 1/8	5 6/12	6 6/10	8 1/4
65	4 3/16	5 7/12	6 7/10	8 3/8
66	4 1/4	5 8/12	6 8/10	8 1/2
67	4 5/16	5 9/12	6 9/10	8 5/8
68	4 3/8	5 10/12	7	8 3/4
69	4 7/16	5 11/12	7 1/10	8 7/8
70	4 1/2	6	7 2/10	9
71	4 9/16	6 1/12	7 3/10	9 1/8
72	4 5/8	6 2/12	7 4/10	9 1/4
73	4 11/16	6 3/12	7 5/10	9 3/8
74	4 3/4	6 4/12	7 6/10	9 1/2
75	4 13/16	6 5/12	7 7/10	9 5/8
76	4 7/8	6 6/12	7 8/10	9 3/4
77	4 15/16	6 7/12	7 9/10	9 7/8
78	5	6 8/12	8	10
79	5 1/16	6 9/12	8 1/10	10 1/8
80	5 1/8	6 10/12	8 2/10	10 1/4
81	5 3/16	6 11/12	8 3/10	10 3/8
82	5 1/4	7	8 4/10	10 1/2
83	5 5/16	7 1/12	8 5/10	10 5/8
84	5 3/8	7 2/12	8 6/10	10 3/4
85	5 7/16	7 3/12	8 7/10	10 7/8
86	5 1/2	7 4/12	8 8/10	11
87	5 9/16	7 5/12	8 9/10	11 1/8
88	5 5/8	7 6/12	9	11 1/4
89	5 11/16	7 7/12	9 1/10	11 3/8
90	5 3/4	7 8/12	9 2/10	11 1/2
91	5 13/16	7 9/12	9 3/10	11 5/8

BROWN AND SHARPE INVOLUTE GEAR-TOOTH CUTTERS

No. 1 will cut wheels from 135 teeth to a rack.
No. 1½ will cut wheels from 80 teeth to 134 teeth.
No. 2 will cut wheels from 55 teeth to 134 teeth.
No. 2½ will cut wheels from 42 teeth to 54 teeth.
No. 3 will cut wheels from 35 teeth to 54 teeth.
No. 3½ will cut wheels from 30 teeth to 34 teeth.
No. 4 will cut wheels from 26 teeth to 34 teeth.
No. 4½ will cut wheels from 23 teeth to 25 teeth.
No. 5 will cut wheels from 21 teeth to 25 teeth.
No. 5½ will cut wheels from 19 teeth to 20 teeth.
No. 6 will cut wheels from 17 teeth to 20 teeth.
No. 6½ will cut wheels from 15 teeth to 16 teeth.
No. 7 will cut wheels from 14 teeth to 16 teeth.
No. 7½ will cut wheels from 13 teeth to 14 teeth.
No. 8 will cut wheels from 12 teeth to 13 teeth.

The eight cutters represented by the whole numbers constitute the regular set of cutters generally used for each pitch of tooth. The half numbers increase the set to 15 and give teeth which are theoretically more correct. In some work special cutters are used for each gear but the 15 cutters in a set offer all that most cases require.

TABLE 10.—DEPTH OF SPACE AND THICKNESS OF TOOTH IN SPUR WHEELS, WHEN CUT WITH THESE CUTTERS

Pitch of Cutter	Depth to be cut in Gear Inches	Thickness of Tooth at Pitch Line. Inches	Pitch of Cutter	Depth to be cut in Gear Inches	Thickness of Tooth at Pitch Line. Inches
1¼	1.726	1.257	11	.196	.143
1½	1.438	1.047	12	.180	.131
1¾	1.233	.898	14	.154	.112
2	1.078	.785	16	.135	.098
2¼	.958	.697	18	.120	.087
2½	.863	.628	20	.108	.079
2¾	.784	.570	22	.098	.071
3	.719	.523	24	.090	.065
3½	.616	.448	26	.083	.060
4	.539	.393	28	.077	.056
5	.431	.314	30	.072	.052
6	.359	.262	32	.067	.049
7	.308	.224	36	.060	.044
8	.270	.196	40	.054	.039
9	.240	.175	48	.045	.033
10	.216	.157			

To measure a gear cutter use the distance from the pitch line to the bottom of the space. Cutters for bevel gears are made approximately to the width of the space at the small end of the teeth where the face is one-third the apex.

CORRECTIONS FOR LONG ADDENDUM SPUR GEARS

If one of two meshing gears of standard design has less than thirty-two teeth, interference occurs unless the teeth are undercut. This becomes serious when twenty-five or fewer teeth are used. By applying the "long and short addendum" method of gear design, interference and undercutting are eliminated by lengthening the addendum of the pinion teeth with a corresponding shortening of the gear-teeth addendum. The whole depth of the teeth and the center distance of the gears remain the same as in the standard design; however, if the center distance is not important it is only necessary to increase the addendum of the pinion teeth. Formulas have been developed in connection with this method of gear design which give the full correction for pinion and gear teeth addenda to eliminate completely both interference and undercutting.

For gears with a small number of teeth, full correction may be undesirable because it gives too pointed a tooth. Half corrections are entirely practical, resulting in minimum undercutting and a tooth almost as strong as one fully corrected. This is especially true of very small gears.

For this half correction, the amount the addendum of the pinion teeth must be lengthened, and the amount the gear-teeth addendum must be shortened if it be desired to retain exact center distance between the gears, can be obtained from the formula

$$\text{Correction} = A - \frac{\text{P.D.}}{2}(\sin\theta)^2$$

where A is the normal addendum, P.D. is the pitch diameter, and θ is the pressure angle.

For example, if 24 is the diametral pitch of a six-tooth pinion having a pressure angle of 14½ degrees, a normal outside diameter of 0.3334 inch, and a normal addendum of 0.0417 inch, the correction would be

$$0.0417 - \frac{0.25}{2} \times 0.25038^2 = 0.0338 \text{ inch}$$

Thus the corrected pitch diameter will be 0.25 + 0.0338 = 0.2838 in., and the corrected outside diameter of the pinion will be 0.3334 + 0.0338 = 0.3672 inch. If it should be necessary to retain the center distance of the normal gears, this correction of 0.0338 inch would have to be subtracted from the normal pitch and outside gear diameters.

Such corrections for spur gears with a 14½-degree pressure angle, five to twenty-five teeth, and 8 to 48 diametral pitch are given in the accompanying table. For gears having a diametral pitch other than those given in the table, the correction is obtained by dividing the constant in the second column by the diametral pitch given.

These corrections for small spur gears give tooth shapes which have been found practical in the manufacture of precise instruments.

TABLE 10a.—ADDENDUM CORRECTIONS[2] FOR SPUR GEARS WITH 25 TEETH OR LESS

(John Apelskog)

Number of Teeth	Constant[1]	Diametral Pitch									
		8	10	11	12	14	16	20	24	32	48
5	0.8433	0.1054	0.0843	0.0766	0.0703	0.0602	0.0527	0.0422	0.0351	0.0263	0.0176
6	0.8110	0.1012	0.0811	0.0737	0.0675	0.0579	0.0507	0.0405	0.0338	0.0253	0.0169
7	0.7810	0.0976	0.0781	0.0710	0.0650	0.0557	0.0487	0.0390	0.0325	0.0244	0.0162
8	0.7490	0.0936	0.0749	0.0680	0.0624	0.0535	0.0467	0.0374	0.0312	0.0234	0.0156
9	0.7185	0.0898	0.0718	0.0653	0.0598	0.0513	0.0448	0.0359	0.0299	0.0224	0.0149
10	0.6875	0.0859	0.0687	0.0624	0.0573	0.0491	0.0428	0.0343	0.0286	0.0215	0.0143
11	0.6550	0.0819	0.0655	0.0595	0.0546	0.0468	0.0408	0.0327	0.0273	0.0204	0.0136
12	0.6240	0.0780	0.0624	0.0567	0.0520	0.0445	0.0390	0.0312	0.0260	0.0195	0.0130
13	0.5925	0.0741	0.0592	0.0538	0.0494	0.0423	0.0370	0.0296	0.0247	0.0183	0.0123
14	0.5610	0.0701	0.0561	0.0510	0.0467	0.0400	0.0350	0.0280	0.0234	0.0175	0.0117
15	0.5300	0.0662	0.0530	0.0482	0.0441	0.0378	0.0331	0.0265	0.0221	0.0166	0.0110
16	0.4985	0.0623	0.0498	0.0453	0.0416	0.0356	0.0312	0.0249	0.0208	0.0156	0.0104
17	0.4671	0.0584	0.0467	0.0424	0.0389	0.0334	0.0292	0.0233	0.0195	0.0146	0.0097
18	0.4358	0.0545	0.0436	0.0396	0.0363	0.0311	0.0272	0.0218	0.0182	0.0136	0.0091
19	0.4044	0.0506	0.0404	0.0367	0.0337	0.0289	0.0253	0.0202	0.0168	0.0126	0.0084
20	0.3731	0.0466	0.0373	0.0339	0.0311	0.0266	0.0233	0.0186	0.0156	0.0117	0.0078
21	0.3417	0.0427	0.0342	0.0311	0.0285	0.0244	0.0213	0.0171	0.0142	0.0107	0.0071
22	0.3104	0.0387	0.0310	0.0282	0.0258	0.0222	0.0194	0.0155	0.0129	0.0097	0.0065
23	0.2790	0.0349	0.0279	0.0253	0.0232	0.0199	0.0174	0.0139	0.0116	0.0087	0.0058
24	0.2477	0.0309	0.0248	0.0225	0.0206	0.0177	0.0154	0.0124	0.0103	0.0077	0.0052
25	0.2164	0.0270	0.0216	0.0196	0.0180	0.0154	0.0135	0.0108	0.0090	0.0067	0.0045

[1] This constant divided by diametral pitch gives the addendum correction for gears of any diametral pitch and with five to twenty-five teeth. For a gear having six teeth and a diametral pitch of 28, the correction would be $\frac{0.811}{28} = 0.029$ inch.

[2] These corrections are to be added to pinion-teeth addenda, and subtracted from gear-teeth addenda, to prevent interference and eliminate excessive undercutting. If the center distance of any two gears is not important, it is only necessary to add the correction to the pinion addendum.

THE DIMENSIONS OF GEARS BY METRIC PITCH

Module is the pitch diameter in millimeters divided by the number of teeth in the gear.

Pitch diameter in millimeters is the module multiplied by the number of teeth in the gear.

M = module.
D = the pitch diameter of gear.
D = the whole diameter of gear.
N = the number of teeth in gear.
D'' = the working depth of teeth.
t = thickness of teeth on pitch line.
f = amount added to depth for clearance.

Then

$$M = \frac{D'}{N} \text{ or } \frac{D}{N + 2}.$$

$$D' = N\ M.$$

$$D = (N + 2)\ M.$$

$$N = \frac{D'}{M} \text{ or } \frac{D}{M} - 2.$$

$$D'' = 2M.$$

$$t = M\ 1.5708.$$

$$f = \frac{M\ 1.5708}{10} = 0.157\ M.$$

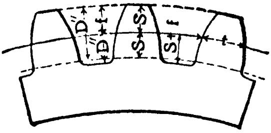


FIG. 11.—Metric Gears

The module is equal to the part marked S in Fig. 11, measured in millimeters and parts of millimeters.

EXAMPLE.—Module = 3.50 millimeters 100 teeth.
P.D. = 3.5 × 100 = 350 millimeters.
Whole diameter = (100 + 2) × 3.5 = 357 millimeters.

TABLE 11.—PITCHES COMMONLY USED—MODULE IN MILLIMETERS

Module	Corresponding English Diametral Pitch	Module	Corresponding English Diametral Pitch
½ mm.	50.800	4.5 mm.	5.644
¾	33.867	5	5.080
1	25.400	5.5	4.618
1.25	20.320	6	4.233
1.5	16.933	7	3.628
1.75	14.514	8	3.175
2	12.700	9	2.822
2.25	11.288	10	2.540
2.5	10.160	11	2.309
2.75	9.236	12	2.117
3	8.466	14	1.814
3.5	7.257	16	1.587
4	6.350		

Measuring Spur Gears by the Use of Pins

Spur-gear teeth may be accurately sized by placing pins or rolls between the teeth and measuring the distance over the pins with a micrometer. To avoid the necessity of calculating every measurement, the accompanying table (on page 256) has been worked out.

TABLE 12.—PIN MEASUREMENTS FOR SPUR-GEAR TOOTH INSPECTION

1 D.P.—Size of Gear Teeth over Pins 1.750 in Diameter for 1 Diametral Pitch

Teeth	Diam. of Pins Used		Even Teeth						
	Pitch	Size of Pin	14½°	17½°	20°	22½°	25°	27½°	30°
8	1	1.7500	10.389	10.389	10.394	10.403	10.416	10.432	10.451
10	2	0.8750	12.415	12.411	12.413	12.420	12.431	12.445	12.462
12	3	0.5834	14.436	14.429	14.428	14.433	14.442	14.455	14.471
14	4	0.4375	16.454	16.442	16.440	16.443	16.450	16.462	16.478
16	5	0.3500	18.468	18.454	18.450	18.451	18.457	18.468	18.483
18	6	0.2917	20.482	20.464	20.458	20.457	20.463	20.473	20.487
20	7	0.2500	22.493	22.473	22.465	22.463	22.468	22.478	22.491
22	8	0.2188	24.502	24.479	24.470	24.468	24.472	24.481	24.494
24	9	0.1944	26.512	26.487	26.475	26.472	26.475	26.484	26.497
26	10	0.1750	28.520	28.492	28.481	28.476	28.479	28.487	28.499
28	12	0.1458	30.526	30.497	30.484	30.479	30.482	30.489	30.501
30	14	0.1250	32.532	32.500	32.487	32.482	32.484	32.491	32.502
32			34.536	34.505	34.491	34.484	34.486	34.492	34.504
34			36.542	36.509	36.494	36.487	36.488	36.493	36.506
36			38.547	38.512	38.496	38.489	38.489	38.495	38.506
38			40.553	40.516	40.499	40.490	40.491	40.496	40.507
40			42.557	42.519	42.502	42.492	42.492	42.498	42.508
42			44.561	44.523	44.503	44.495	44.493	44.499	44.509
52			54.576	54.533	54.510	54.500	54.498	54.502	54.513
72			74.597	74.546	74.521	74.507	74.504	74.510	74.518
102			104.616	104.557	104.528	104.513	104.511	104.513	104.521
142			144.625	144.562	144.535	144.514	144.514	144.514	144.523

Odd Teeth

9			11.256	11.254	11.258	11.265	11.277	11.291	11.309
11			13.307	13.301	13.302	13.308	13.318	13.331	13.348
13			15.346	15.336	15.335	15.338	15.347	15.359	15.375
15			17.376	17.362	17.359	17.361	17.368	17.379	17.395
17			19.400	19.384	19.378	19.379	19.384	19.395	19.490
19			21.420	21.402	21.394	21.393	21.398	21.408	21.422
21			23.437	23.415	23.406	23.405	23.409	23.418	23.432
23			25.452	25.428	25.417	25.415	25.419	25.427	25.440
25			27.464	27.438	27.427	27.423	27.427	27.434	27.447
27			29.476	29.448	29.435	29.431	29.433	29.441	29.453
29			31.485	31.456	31.442	31.437	31.439	31.446	31.458
31			33.495	33.463	33.449	33.443	33.444	33.451	33.462
33			35.503	35.469	35.454	35.448	35.448	35.455	35.466
35			37.511	37.476	37.460	37.453	37.453	37.459	37.470
37			39.516	39.480	39.463	39.455	39.455	39.461	39.472
39			41.523	41.485	41.467	41.459	41.458	41.465	41.475
41			43.529	43.489	43.472	43.463	43.463	43.467	43.478
43			45.534	45.493	45.475	45.465	45.465	45.470	45.481
53			55.554	55.508	55.486	55.477	55.474	55.479	55.490
73			75.580	75.530	75.505	75.490	75.487	75.492	75.500
103			105.600	105.544	105.513	105.499	105.496	105.500	105.507
143			145.619	145.555	145.526	145.506	145.506	145.507	145.518

This table is by Sam Trimbath and is based on the use of pins 1.750 inch in diameter for 1 diametral pitch gears. While some retain this size of pin, there is a trend toward a pin of 1.728 inch in diameter as shown in the tables by H. L. Van Keuren, page 1427 n the Wartime Data Supplement. He also uses pins 1.44 inch in diameter for internal gears instead of 1.6 as was formerly considered correct. Tables for internal gear measurement are also given in the Wartime Data Supplement.

It will be noted that the same size of pin is used for the same pitch regardless of the number of teeth.

The sizes given in the preceding table are for gears of 1 diametral pitch, and since gears of 5, 7, and 10 pitch are $\frac{1}{5}$, $\frac{1}{7}$ and $\frac{1}{10}$ the size of one pitch, the size over pins will be $\frac{1}{5}$, $\frac{1}{7}$ or $\frac{1}{10}$ the size given in the table, provided a pin $\frac{1}{5}$, $\frac{1}{7}$ or $\frac{1}{10}$ the size used in calculating the table is used. The size of pin used for 1 pitch is 1.750 inches; therefore, the size of pin to use for 5 pitch is 0.350 inch; for 7 pitch, 0.250 inch; for 10 pitch, 0.175 inch, etc.

As the number of teeth increases, the more nearly straight the teeth become. Between 10 and 12 teeth, in gears having 20-degree pressure angle, there is a difference of 2.000 parts of the pitch in the pitch diameter, whereas the difference over the pins in gears of 14½-degree pressure angle is 2.021 parts of the pitch. Between 40 and 42 teeth, there is again a difference in pitch diameter of 2.000, whereas the difference over the pins between gears of 20- and 14½-degree pressure angle is 2.004 parts of the pitch. Here the teeth become straight enough to jump from 42 to 52 teeth, then to 72, 102, 142, leaving the missing numbers to be found by interpolation.

To find size over pins, divide the figure in column under the pressure angle and opposite the number of teeth, by the pitch.

EXAMPLE.—Thirty-tooth, $\frac{7}{9}$ pitch, 20-degree pressure angle: table gives 32.487 in 20-degree column for 30 teeth; divide this by pitch, which is 7.00; $\frac{32.487}{7} = 4.641$ in diameter over pins.

Sizes given are standard; no backlash allowed; tooth and tooth space are taken as equal. For pitches finer than 1 diametral pitch, divide the figure opposite the number of teeth, in the column corresponding to the pressure angle, by the pitch. To obtain the pin diameter, divide 1.750 inches by the pitch.

EXAMPLE.—Twenty-tooth, 10-pitch, 25-degree pressure angle:

$$\frac{22.468}{10} = 2.2468 = \text{size over pins.}$$

The size for gears having numbers of teeth not shown, such as between 42 and 52, can be found readily by interpolation. When interpolating, care should be taken to use the upper half of the table if the teeth are even in number, and the lower half if the teeth are odd in number. Thus, the size of a 47-tooth gear would be found between 43 and 53, not between 42 and 52.

For numbers of teeth greater than 142 and 143, a close approximation can be found readily by adding two for every two teeth greater, to the figures for 142, if even, and for 143, if odd. For a pressure angle falling between those given in Table 12 a close approximation can be obtained by interpolation. The greatest difference is between 27½ and 30 degrees for an 8-tooth gear, and this is only 0.019 inch. If the figure for 27½-degree pressure angle had been used on a 30-degree pressure angle for a 10-pitch gear, the error would be 0.0019. Assuming a pressure angle of 29 degrees and adding $\frac{3}{5}$ of 0.019 to the figure for 27½ degrees, the result is 10.442. Actual calculation gives 10.443, an error of only 0.001 for a 1-diametral-pitch gear, or 0.0001 for a 10-diametral-pitch gear. When it is considered that these errors are in diameter and that the errors in tooth thickness are approximately half again as large, these figures will be seen to have sufficient accuracy. Two wires are used for both odd- and even-toothed gears.

A Table for Dimensions for Miter Gears

The table on page 260 is of service in determining the principal dimensions of miter gears (center angle 45 degrees), the number of teeth and the pitch being known. The table covers most of the possible number of teeth from 12 to 60, inclusive, and pitches from 2 to 10, inclusive, omitting 9. Values for face and cut angles correspond with designations in Fig. 12.

BEVEL GEARS

Bevel gears are used to transmit power when shafts are not parallel. They can be made for any angle but are most often at right angles. Right-angle bevel gears having the same number of teeth are often called "miter" gears. The teeth are, or should be, radial so that they are larger at the outer end. The names of parts are shown in Fig. 12. These should be noted carefully, particularly the face angles. The earlier editions measured *face angle* at right angles to the axis, but this is now changed as shown.

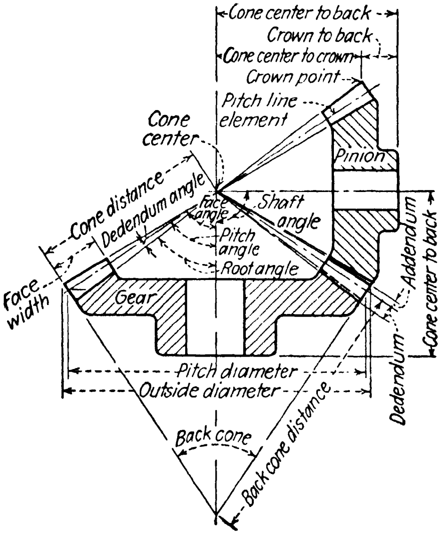


Fig. 12.—Conventional Bevel Gear Nomenclature. See Remarks under Face Angles (p. 266*a*) and Gage Angle. (p. 266*b*).

Laying Out Bevel-Gear Blanks

In laying out bevel gears, first decide upon the pitch, and draw the center lines *BB* and *CC*, intersecting at right angles at *A* as shown in Fig. 13. Then draw the lines *DD* to *EE* the same distance each side of *BB* and parallel to it; the distance from *DD* to *EE*

TABLE 13.—DIMENSIONS FOR MITER GEARS

MITER GEARS, CENTER ANGLE 45 DEGREES

No. of Teeth	Pitch Diameters								Outside Diameters								Face Angle	Cut Angle
	2 P.	3 P.	4 P.	5 P.	6 P.	7 P.	8 P.	10P.	2 P.	3 P.	4 P.	5 P.	6 P.	7 P.	8 P.	10P.		
12	6	4	3	$2\frac{2}{5}$	2	$1\frac{5}{7}$	$1\frac{1}{2}$	$1\frac{2}{10}$	6.71	4.48	3.35	2.68	2.24	1.92	1.68	1.34	51°43′	37°14′
13	$6\frac{1}{2}$	$4\frac{1}{3}$	$3\frac{1}{4}$	$2\frac{3}{5}$	$2\frac{1}{6}$	$1\frac{6}{7}$	$1\frac{5}{8}$	$1\frac{3}{10}$	7.21	4.80	3.60	2.88	2.40	2.06	1.81	1.44	51°12′	37°49′
14	7	$4\frac{2}{3}$	$3\frac{1}{2}$	$2\frac{4}{5}$	$2\frac{2}{6}$	2	$1\frac{3}{4}$	$1\frac{4}{10}$	7.71	5.14	3.85	3.08	2.57	2.20	1.93	1.54	50°47′	38°20′
15	$7\frac{1}{2}$	5	$3\frac{3}{4}$	3	$2\frac{3}{6}$	$2\frac{1}{7}$	$1\frac{7}{8}$	$1\frac{5}{10}$	8.21	5.46	4.10	3.28	2.73	2.35	2.06	1.64	50°23′	38°46′
16	8	$5\frac{1}{3}$	4	$3\frac{1}{5}$	$2\frac{4}{6}$	$2\frac{2}{7}$	2	$1\frac{6}{10}$	8.71	5.80	4.35	3.48	2.90	2.49	2.18	1.74	50°03′	39°09′
17	$8\frac{1}{2}$	$5\frac{2}{3}$	$4\frac{1}{4}$	$3\frac{2}{5}$	$2\frac{5}{6}$	$2\frac{3}{7}$	$2\frac{1}{8}$	$1\frac{7}{10}$	9.21	6.14	4.60	3.68	3.07	2.63	2.31	1.84	49°45′	39°30′
18	9	6	$4\frac{1}{2}$	$3\frac{3}{5}$	3	$2\frac{4}{7}$	$2\frac{1}{4}$	$1\frac{8}{10}$	9.71	6.48	4.85	3.88	3.24	2.77	2.43	1.94	49°29′	39°48′
19	$9\frac{1}{2}$	$6\frac{1}{3}$	$4\frac{3}{4}$	$3\frac{4}{5}$	$3\frac{1}{6}$	$2\frac{5}{7}$	$2\frac{3}{8}$	$1\frac{9}{10}$	10.21	6.80	5.10	4.08	3.40	2.92	2.56	2.04	49°15′	40°04′
20	10	$6\frac{2}{3}$	5	4	$3\frac{2}{6}$	$2\frac{6}{7}$	$2\frac{1}{2}$	2	10.71	7.14	5.35	4.28	3.57	3.06	2.68	2.14	49°03′	40°19′
21	$10\frac{1}{2}$	7	$5\frac{1}{4}$	$4\frac{1}{5}$	$3\frac{3}{6}$	3	$2\frac{5}{8}$	$2\frac{1}{10}$	11.21	7.46	5.60	4.48	3.73	3.20	2.81	2.24	48°51′	40°32′
22	11	$7\frac{1}{3}$	$5\frac{1}{2}$	$4\frac{2}{5}$	$3\frac{4}{6}$	$3\frac{1}{7}$	$2\frac{3}{4}$	$2\frac{2}{10}$	11.71	7.80	5.85	4.68	3.90	3.35	2.93	2.34	48°41′	40°45′
23	$11\frac{1}{2}$	$7\frac{2}{3}$	$5\frac{3}{4}$	$4\frac{3}{5}$	$3\frac{5}{6}$	$3\frac{2}{7}$	$2\frac{7}{8}$	$2\frac{3}{10}$	12.21	8.14	6.10	4.88	4.07	3.49	3.06	2.44	48°31′	40°56′
24	12	8	6	$4\frac{4}{5}$	4	$3\frac{3}{7}$	3	$2\frac{4}{10}$	12.71	8.48	6.35	5.08	4.24	3.63	3.18	2.54	48°22′	41°06′
25	$12\frac{1}{2}$	$8\frac{1}{3}$	$6\frac{1}{4}$	5	$4\frac{1}{6}$	$3\frac{4}{7}$	$3\frac{1}{8}$	$2\frac{5}{10}$	13.21	8.80	6.60	5.28	4.40	3.77	3.31	2.64	48°14′	41°15′
26	13	$8\frac{2}{3}$	$6\frac{1}{2}$	$5\frac{1}{5}$	$4\frac{2}{6}$	$3\frac{5}{7}$	$3\frac{1}{4}$	$2\frac{6}{10}$	13.71	9.14	6.85	5.48	4.57	3.92	3.43	2.74	48°07′	41°24′
27	$13\frac{1}{2}$	9	$6\frac{3}{4}$	$5\frac{2}{5}$	$4\frac{3}{6}$	$3\frac{6}{7}$	$3\frac{3}{8}$	$2\frac{7}{10}$	14.21	9.46	7.10	5.68	4.73	4.06	3.56	2.84	48°00′	41°32′
28	14	$9\frac{1}{3}$	7	$5\frac{3}{5}$	$4\frac{4}{6}$	4	$3\frac{1}{2}$	$2\frac{8}{10}$	14.71	9.80	7.35	5.88	4.90	4.20	3.68	2.94	47°54′	41°39′
29	$14\frac{1}{2}$	$9\frac{2}{3}$	$7\frac{1}{4}$	$5\frac{4}{5}$	$4\frac{5}{6}$	$4\frac{1}{7}$	$3\frac{5}{8}$	$2\frac{9}{10}$	15.21	10.14	7.60	6.08	5.07	4.35	3.81	3.04	47°47′	41°46′
30	15	10	$7\frac{1}{2}$	6	5	$4\frac{2}{7}$	$3\frac{3}{4}$	3	15.71	10.48	7.85	6.28	5.24	4.49	3.93	3.14	47°42′	41°53′
31	$15\frac{1}{2}$	$10\frac{1}{3}$	$7\frac{3}{4}$	$6\frac{1}{5}$	$5\frac{1}{6}$	$4\frac{3}{7}$	$3\frac{7}{8}$	$3\frac{1}{10}$	16.21	10.80	8.10	6.48	5.40	4.63	4.06	3.24	47°37′	41°59′
32	16	$10\frac{2}{3}$	8	$6\frac{2}{5}$	$5\frac{2}{6}$	$4\frac{4}{7}$	4	$3\frac{2}{10}$	16.71	11.14	8.35	6.68	5.57	4.77	4.18	3.34	47°32′	42°04′
33	$16\frac{1}{2}$	11	$8\frac{1}{4}$	$6\frac{3}{5}$	$5\frac{3}{6}$	$4\frac{5}{7}$	$4\frac{1}{8}$	$3\frac{3}{10}$	17.21	11.46	8.60	6.88	5.73	4.92	4.31	3.44	47°27′	42°10′
34	17	$11\frac{1}{3}$	$8\frac{1}{2}$	$6\frac{4}{5}$	$5\frac{4}{6}$	$4\frac{6}{7}$	$4\frac{1}{4}$	$3\frac{4}{10}$	17.71	11.80	8.85	7.08	5.90	5.06	4.43	3.54	47°23′	42°15′
35	$17\frac{1}{2}$	$11\frac{2}{3}$	$8\frac{3}{4}$	7	$5\frac{5}{6}$	5	$4\frac{3}{8}$	$3\frac{5}{10}$	18.21	12.14	9.10	7.28	6.07	5.20	4.56	3.64	47°19′	42°19′
36	18	12	9	$7\frac{1}{5}$	6	$5\frac{1}{7}$	$4\frac{1}{2}$	$3\frac{6}{10}$	18.71	12.48	9.35	7.48	6.24	5.35	4.68	3.74	47°15′	42°24′
37	$18\frac{1}{2}$	$12\frac{1}{3}$	$9\frac{1}{4}$	$7\frac{2}{5}$	$6\frac{1}{6}$	$5\frac{2}{7}$	$4\frac{5}{8}$	$3\frac{7}{10}$	19.21	12.80	9.60	7.68	6.40	5.49	4.81	3.84	47°11′	42°28′
38	19	$12\frac{2}{3}$	$9\frac{1}{2}$	$7\frac{3}{5}$	$6\frac{2}{6}$	$5\frac{3}{7}$	$4\frac{3}{4}$	$3\frac{8}{10}$	19.71	13.14	9.85	7.88	6.57	5.63	4.93	3.94	47°08′	42°32′
40	20	$13\frac{1}{3}$	10	8	$6\frac{4}{6}$	$5\frac{5}{7}$	5	4	20.71	13.80	10.35	8.28	6.90	5.92	5.18	4.14	47°01′	42°39′
42	21	14	$10\frac{1}{2}$	$8\frac{2}{5}$	7	6	$5\frac{1}{4}$	$4\frac{2}{10}$	21.71	14.48	10.85	8.68	7.24	6.20	5.43	4.34	46°56′	42°46′
44	22	$14\frac{2}{3}$	11	$8\frac{4}{5}$	$7\frac{2}{6}$	$6\frac{2}{7}$	$5\frac{1}{2}$	$4\frac{4}{10}$	22.71	15.14	11.35	9.08	7.57	6.49	5.68	4.54	46°50′	42°52′
46	23	$15\frac{1}{3}$	$11\frac{1}{2}$	$9\frac{1}{5}$	$7\frac{4}{6}$	$6\frac{4}{7}$	$5\frac{3}{4}$	$4\frac{6}{10}$	23.71	15.80	11.85	9.48	7.90	6.77	5.93	4.74	46°46′	42°58′
48	24	16	12	$9\frac{3}{5}$	8	$6\frac{6}{7}$	6	$4\frac{8}{10}$	24.71	16.48	12.35	9.88	8.24	7.06	6.18	4.94	46°42′	43°06′
50	25	$16\frac{2}{3}$	$12\frac{1}{2}$	10	$8\frac{2}{6}$	$7\frac{1}{7}$	$6\frac{1}{4}$	5	25.71	17.14	12.85	10.28	8.57	7.35	6.43	5.14	46°37′	43°12′
54	27	18	$13\frac{1}{2}$	$10\frac{4}{5}$	9	$7\frac{5}{7}$	$6\frac{3}{4}$	$5\frac{4}{10}$	27.71	18.48	13.85	11.08	9.24	7.92	6.93	5.54	46°31′	43°18′
58	29	$19\frac{1}{3}$	$14\frac{1}{2}$	$11\frac{3}{5}$	$9\frac{4}{6}$	$8\frac{2}{7}$	$7\frac{1}{4}$	$5\frac{8}{10}$	29.71	19.80	14.85	11.88	9.90	8.49	7.43	5.94	46°24′	43°24′
60	30	20	15	12	10	$8\frac{4}{7}$	$7\frac{1}{2}$	6	30.71	20.48	15.35	12.28	10.24	8.77	7.68	6.14	46°21′	43°30′

being as many eighths of an inch—if it be 8 pitch—as there are to be teeth in the gear. In the example, the number of teeth is 24; therefore, the distance from *DD* to *EE* will be $\frac{24}{8}$, or $1\frac{1}{2}$ inches each side of *BB*. *KK* and *LL* are similarly drawn, but there being only 16 teeth in the small gear, the distance from *KK* to *LL* will be $\frac{16}{8}$, or 1 inch each side of *CC*. Then through the intersections of *DD* and *LL*, *EE* and *LL*, and *EE* and *KK*, draw the diagonals *FA*. These are the pitch lines. Through the same point draw lines as *GG* at right angles to the pitch lines, forming the backs of the teeth. On these lines lay off $\frac{1}{8}$ inch each side of the pitch lines, and draw *MA* and *NA*, forming the faces and bottoms of the teeth. The lines *HH* are drawn parallel to *GG*, the distance between them being the width of the face.

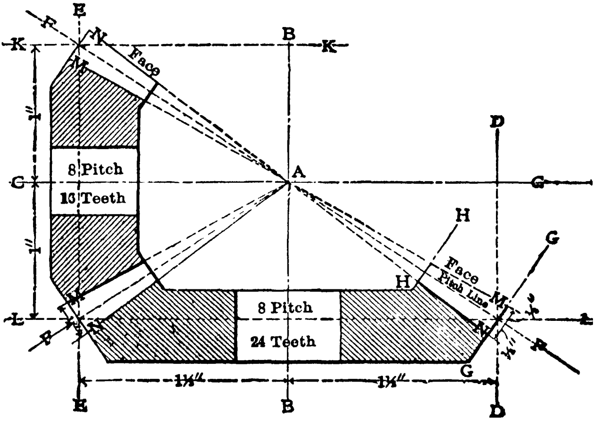


FIG. 13.—Laying Out Bevel Gears

The face of the larger gear should be turned to the lines *MA*, and the small gear to *NA*. For other pitches, the same rules apply. If 4 pitch, use fourths, instead of eighths; if 3 pitch, thirds, etc.

Bevel bears should always be turned to the exact diameters and angles of the drawings and the teeth cut at the correct angle.

Proportions of Miter and Bevel Gears

To find the pitch or center angle:

Divide the number of teeth in the gear by the number of teeth in the pinion. This gives the tangent of the pitch angle of the gear. Or divide the number of teeth in the pinion by the teeth in the gear, and get the tangent of the pitch angle of the pinion. Subtracting either pitch angle from 90 gives the pitch angle of the other.

To find the outside diameter:

Multiply the cosine of the pitch angle by twice the addendum, and add the pitch diameter.

To find the outside cone radius or apex distance:

Multiply the secant of the pitch angle of the pinion by one-half the pitch diameter of the gear.

Another useful rule is:

The apex distance of a bevel gear or pinion equals its pitch diameter divided by twice the size of its pitch angle or apex distance $= \dfrac{\text{pitch diameter}}{2 \text{ sine of pitch angle}}$.

To find the face and cutting angles:

Divide the addendum by the outside cone radius or apex distance. This gives the tangent of the addendum or outside angle. Subtract this angle from the pitch angle of the pinion to obtain the cutting angle of the pinion and the face angle of the gear. Subtract the same addendum angle from the center angle of the gear to obtain the cutting angle of the gear and the face angle of the pinion. This gives a uniform clearance and is especially for use with rotary cutters.

To find height of addendum at small end of tooth:

Divide the addendum at the large end of the tooth by the outside cone radius. This gives the decrease in height of the addendum for each inch of gear face. Multiply this by the length of the gear face, and subtract the result from the addendum of the large end of the tooth. The difference is the height of the addendum at the small end of the tooth.

Cutters for Bevel Gears

Lay out the bevel gears and draw lines A and B at right angles to the center angle line. Extend this to the center lines, and measure A and B. The distance A = the *radius* of a spur gear of the same pitch, and finding the number of teeth in such a gear, we have the right cutter for the bevel gear in question. If the gears are 8 pitch and the distance A = 4 inches, multiply these together and by 2 to get the diameter. Then $2 \times 4 \times 8 = 64$ teeth, so that a No. 2 cutter is the one to use. For the pinion, if B = 2 inches, then $2 \times 2 \times 8 = 32$, or a No. 4 cutter is the one to use.

SETTING CUTTER OUT OF CENTER

The cutter can be no thicker than the space at the small end of the teeth, so it is necessary to set it out of center and rotate the blank to make the space right at the large end of the teeth. The amount of this setover can be found by the following rule and table of the Brown & Sharpe Mfg. Co.

Divide distance A, Fig. 14, by the width of the face. Find the factor in the table for this ratio and the cutter to be used. Divide this factor by the diametral pitch, and subtract the quotient from half the thickness of the cutter at the pitch line. As a formula this is:

$$\text{Setover} = \frac{Tc}{2} - \frac{\text{factor in table}}{P}.$$

Tc = thickness of cutter used at pitch line.
P = diametral pitch of gear to be cut.

EXAMPLE.—To cut a bevel gear of 24 teeth, 6 pitch, 30-degree pitch cone angle and 1¼-inch face. Divide the number of teeth by the cosine of the center angle *CG*, Fig. 14, which is 0.866. As 24 ÷ 0.866 is 27 +, we select a No. 4 cutter. The apex distance is 4 inches, and dividing this by the face, 1¼ inches = 3.2:1. The second column of the table contains this ratio, and opposite No. 4 cutter is 0.280. Because the face of this gear is about one-third the apex and the cutter must be thin enough for the inner end, we use a cutter for 9 pitch, which is 0.1745 inch thick at the pitch line, in Table 14. The setover then is

$$\frac{0.1745}{2} - \frac{0.280}{6} = 0.0406 \text{ inch.}$$

First set cutter central with index head. Set head to proper cutting angle. Set dial on cross-feed to zero. Index and cut two or three grooves to depth. Set cutter out of center 0.04 inch, and note adjustment on cross-feed dial. Rotate gear in opposite direction to setover until the side of the cutter nearest the center line cuts the entire surface of teeth. Reverse this for the other side, and measure teeth at both ends. If teeth at large end are too thick when the small end is correct, increase the setover. If the small end is too thick when the large end is right, decrease the setover. Adjust accordingly.

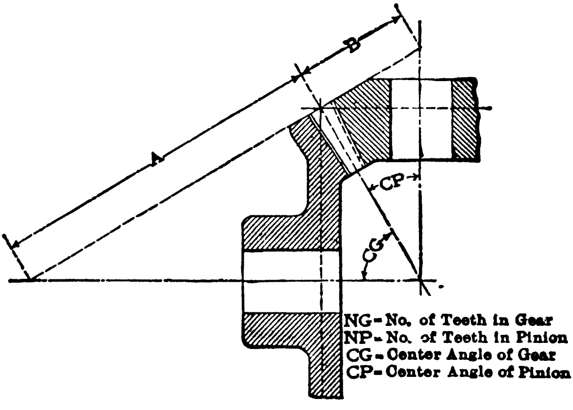

B
A
CP
CG
NG = No. of Teeth in Gear
NP = No. of Teeth in Pinion
CG = Center Angle of Gear
CP = Center Angle of Pinion

FIG. 14.—Finding the Cutter to Use

USING THE BEVEL-GEAR TABLE

Take a pair of bevel gears 24 and 72 teeth, 8 diametral pitch. Divide the pinion by the gear: 24 ÷ 72 = 0.3333. This is the

TABLE 14.—OBTAINED SETOVER FOR CUTTER BEVEL GEARS

Ratio of Apex Distance Width of Face = $\frac{\text{Apex}}{\text{Face}}$

No. of Cutter	$\frac{3}{1}$	$\frac{3\frac{1}{4}}{1}$	$\frac{3\frac{1}{2}}{1}$	$\frac{3\frac{3}{4}}{1}$	$\frac{4}{1}$	$\frac{4\frac{1}{4}}{1}$	$\frac{4\frac{1}{2}}{1}$	$\frac{4\frac{3}{4}}{1}$	$\frac{5}{1}$	$\frac{5\frac{1}{2}}{1}$	$\frac{6}{1}$	$\frac{7}{1}$	$\frac{8}{1}$
1	0.254	0.254	0.255	0.256	0.257	0.257	0.257	0.258	0.258	0.259	0.260	0.262	0.264
2	0.266	0.208	0.271	0.272	0.273	0.274	0.274	0.275	0.277	0.279	0.280	0.283	0.284
3	0.266	0.268	0.271	0.273	0.275	0.278	0.280	0.282	0.283	0.286	0.287	0.290	0.292
4	0.275	0.280	0.285	0.287	0.291	0.293	0.296	0.298	0.298	0.302	0.305	0.308	0.311
5	0.280	0.285	0.290	0.293	0.295	0.296	0.298	0.300	0.302	0.307	0.309	0.313	0.315
6	0.311	0.318	0.323	0.328	0.330	0.334	0.337	0.340	0.343	0.348	0.352	0.356	0.362
7	0.289	0.298	0.308	0.316	0.324	0.329	0.334	0.338	0.343	0.350	0.360	0.370	0.376
8	0.275	0.286	0.296	0.309	0.319	0.331	0.338	0.344	0.352	0.361	0.368	0.380	0.386

tangent of the center angle of pinion. Look in the seven columns under center angles for the nearest number to this. The nearest is 0.3346 in the center column, as all these are decimals to four places. Follow this out to the left and find 18 in the center-angle column. As the 0.3346 is in the column marked 0.50, the center angle of the pinion is 18.50 degrees. Looking to the right under center angles for gears, find 71, and add the 0.50, making the gear angle 71.50 degrees. Thus:

Center angle of pinion 18.5 degrees.
Center angle of gear 71.5 degrees.

In the first column opposite 18 is 36. Divide this by the number of teeth in the pinion, 24, and get 1.5 degrees. This is the angle increase for this pair of gears and is the amount to be added to the center angle to get the face angle and to be deducted to get the cut angles. This gives:

Pinion center angle 18.5 + 1.5 = 20 degrees face angle.
Pinion center angle 18.5 − 1.5 = 17 degrees cut angle.
Gear center angle 71.5 + 1.5 = 73 degrees face angle.
Gear center angle 71.5 − 1.5 = 70 degrees cut angle.

For the outside diameter, go to the column of diameter increase, and in line with 18 find 1.90. Divide this by the pitch, 8, and get 0.237, which is the diameter increase for the pinion. Follow the same line to the right, and find 0.65 for the gear increase. Divide this by the pitch, 0.8, and get 0.081 for gear increase. This gives:

Pinion, 24 teeth, 8 pitch = 3 inches + 0.237 = 3.237 inches outside diameter.

Gear, 72 teeth, 8 pitch = 9 inches + 0.081 = 9.081 inches outside diameter.

TO SELECT THE CUTTER

Another way of selecting the cutter is to divide the number of teeth in the gear by the cosine of the center angle C, and the answer is the number of teeth in a spur gear from which to select the cutter. For the pinion, the process is the same, except that the number of

TABLE 15.—BEVEL GEARS
SHAFT ANGLES 90 DEGREES

Angle Increase; Divide by Teeth in Pinion	Diameter Increase; Divide by Pitch for Pinion	Center Angle Degrees for Pinion	Center Angle Hundredth Degrees							Center Angle Degrees for Gear	Diameter Increase; Divide by Pitch for Gear
			Left-hand Column read here								
			0	.17	.33	.50	.67	.83	1.00		
1	2.00	0	.0000	.0029	.0058	.0087	.0116	.0145	.0175	89	.03
2	2.00	1	.0175	.0204	.0233	.0262	.0291	.0320	.0349	88	.07
4	2.00	2	.0349	.0378	.0407	.0437	.0466	.0495	.0524	87	.10
6	2.00	3	.0524	.0553	.0582	.0612	.0641	.0670	.0699	86	.14
8	1.99	4	.0699	.0729	.0758	.0787	.0816	.0846	.0875	85	.17
10	1.99	5	.0875	.0904	.0934	.0963	.0992	.1022	.1051	84	.21
12	1.99	6	.1051	.1080	.1110	.1139	.1169	.1198	.1228	83	.24
14	1.98	7	.1228	.1257	.1278	.1317	.1346	.1376	.1405	82	.28
16	1.98	8	.1405	.1435	.1465	.1495	.1524	.1554	.1584	81	.31
18	1.98	9	.1584	.1614	.1644	.1673	.1703	.1733	.1763	80	.34
20	1.97	10	.1763	.1793	.1823	.1853	.1883	.1914	.1944	79	.38
22	1.96	11	.1944	.1974	.2004	.2035	.2065	.2095	.2126	78	.41
24	1.96	12	.2126	.2156	.2186	.2217	.2247	.2278	.2309	77	.45
26	1.95	13	.2309	.2339	.2370	.2401	.2432	.2462	.2493	76	.48
28	1.94	14	.2493	.2524	.2555	.2586	.2617	.2648	.2679	75	.51
30	1.93	15	.2679	.2711	.2742	.2773	.2805	.2836	.2867	74	.55
32	1.92	16	.2867	.2899	.2931	.2962	.2994	.3026	.3057	73	.58
34	1.91	17	.3057	.3089	.3121	.3153	.3185	.3217	.3249	72	.62
36	1.90	18	.3249	.3281	.3314	.3346	.3378	.3411	.3443	71	.65
37	1.89	19	.3443	.3476	.3508	.3541	.3574	.3607	.3640	70	.68
39	1.88	20	.3640	.3673	.3706	.3739	.3772	.3805	.3839	69	.71
41	1.86	21	.3839	.3872	.3906	.3939	.3973	.4006	.4040	68	.75
43	1.85	22	.4040	.4074	.4108	.4142	.4176	.4210	.4245	67	.78
45	1.84	23	.4245	.4279	.4314	.4348	.4383	.4417	.4452	66	.81
47	1.82	24	.4452	.4487	.4522	.4557	.4592	.4628	.4663	65	.84
49	1.81	25	.4663	.4699	.4734	.4770	.4806	.4841	.4877	64	.88
50	1.79	26	.4877	.4913	.4950	.4986	.5022	.5059	.5095	63	.91
52	1.78	27	.5095	.5132	.5169	.5206	.5243	.5280	.5317	62	.93
54	1.76	28	.5317	.5354	.5392	.5430	.5467	.5505	.5543	61	.97
56	1.74	29	.5543	.5581	.5619	.5658	.5696	.5735	.5774	60	1.00
57	1.73	30	.5774	.5812	.5851	.5890	.5930	.5969	.6009	59	1.03
59	1.71	31	.6009	.6048	.6088	.6128	.6168	.6208	.6249	58	1.05
61	1.69	32	.6249	.6289	.6330	.6371	.6412	.6453	.6494	57	1.08
63	1.67	33	.6494	.6536	.6577	.6619	.6661	.6703	.6745	56	1.11
64	1.65	34	.6745	.6787	.6830	.6873	.6916	.6959	.7002	55	1.14
66	1.63	35	.7002	.7046	.7089	.7133	.7177	.7221	.7265	54	1.17
68	1.61	36	.7265	.7310	.7355	.7400	.7445	.7490	.7536	53	1.20
69	1.59	37	.7536	.7581	.7627	.7673	.7720	.7766	.7813	52	1.23
71	1.57	38	.7813	.7860	.7907	.7954	.8002	.8050	.8098	51	1.25
72	1.55	39	.8098	.8146	.8195	.8243	.8292	.8342	.8391	50	1.28
73	1.53	40	.8391	.8441	.8491	.8541	.8591	.8642	.8693	49	1.31
75	1.51	41	.8693	.8744	.8796	.8847	.8899	.8952	.9004	48	1.33
77	1.48	42	.9004	.9057	.9110	.9163	.9217	.9271	.9325	47	1.36
79	1.46	43	.9325	.9380	.9435	.9490	.9545	.9601	.9657	46	1.39
80	1.43	44	.9657	.9713	.9770	.9827	.9884	.9942	1.0000	45	1.41
81	1.41	45	1.0000	1.0058	1.0117	1.0176	1.0235	1.0295	1.0355	44	1.43
			1.00	.83	.67	.50	.33	.17	0		

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teeth in the pinion is divided by the sine of the center angle. The formula is:

$$\tan CG = \frac{NG}{NP}. \qquad \tan CP = \frac{NP}{NG}.$$

$$\text{Number of teeth to use in selecting cutter for gear} = \frac{NG}{\cos CG}.$$

$$\text{Number of teeth to use in selecting cutter for pinion} = \frac{NP}{\sin CG}.$$

Any pair of gears can be figured out in the same way, bearing in mind, when finding the center angle for the gear, to read the parts of a degree from the decimals at the bottom, and for the pinion, to read them from the top. In the example worked out, the tangent came in the center column so that it made no difference. If, however, the tangent had been 0.3476, we read the pinion angle at the top, 19.17 degrees, and the gear angle at the bottom, 70.83. By noting that the sum of the two angles is 90 degrees, we can be sure we are right. See page 254 for gear-tooth cutters.

Planing Bevel Gears

Few bevel gears are now cut by milling except in small job shops or in experimental work. Bevel gear teeth are now generated by bevel gear planers of the Gleason or Bilgram type, with tools which move toward the center of the cone made by the tooth angle. This method automatically varies the width of the tooth and the space without the "setover" necessary when the teeth are milled. The following data, by courtesy of the Gleason Works, show modern bevel gear cutting practice.

GLEASON STRAIGHT BEVEL GEAR SYSTEM

The Gleason Straight Bevel Gear System provides a basis for designing straight bevel gears with the most desirable tooth forms for practical operating conditions. It was originally presented to the American Gear Manufacturers Association in April, 1922, by F. E. McMullen and T. M. Durkan of the Gleason Works, and was adopted by the A.G.M.A. later the same year.

It was revised in 1940, and the revision was adopted by the A.G.M.A. in May, 1941. The principal purpose of the revision was to eliminate undercut in all cases and to increase the clearance at the inner ends of the teeth.

General Features

Ratios.—The system is designed to include all ratios in common use. Ratios outside the system can, of course, be designed according to the same general principles used in determining the system.

Working Depth.—The working depth is $\frac{2.000 \text{ inches}}{\text{D. P.}}$.

Clearance.—The clearance at the large end of the teeth is $\frac{0.188 \text{ inch}}{\text{D. P.}}$ for teeth up to 20 D. P. and $\frac{0.250}{\text{D. P.}}$ for 20 D. P. and finer.

Pressure Angle.—The basic pressure angle is 14½ degrees. Certain advantages are generally associated with low pressure angle, such as:

(1) larger contact ratio (that is, greater arc of action)
(2) less effect of eccentricity
(3) smaller radial and axial thrust loads

These advantages are obtained in ratios with sufficiently large numbers of teeth. In certain ratios with small numbers of teeth in the pinion, however, a low pressure angle, together with standard depths, is accompanied by undercut, which decreases the tooth contact and the strength. In the original system a slight amount of undercut was allowed. In the case of ratios where a pressure angle of 14½ degrees would result in excessive undercut, however, pressure angles of 17½ or 20 degrees were specified.

In the revised system, undercut is eliminated in *all* cases by extending the range of ratios for which pressure angles of 17½ and 20 degrees are used.

Addendums.—As in the original system, long and short addendums have been adopted for all ratios except those with equal numbers of teeth. A long-addendum pinion and a short-addendum gear have more action in excess than in approach (with pinion driving), have stronger pinion teeth, and can have a lower pressure angle without undercut.

Face Angles

Face angles in the original system made the apex of the face cone coincide with the apex of the pitch cone, as shown in Fig. 12. Before the revision this was always the practice in gear design. In the revised system, however, face angles are changed to make the face cone of a blank parallel to the root cone of its mate as shown in Fig. 14*a*. This results in constant clearance along the tooth and is done so that larger edge radii can be used on generating tools without fillet interference at the small ends of the teeth. It is well known that with a larger fillet at the base of a tooth, stress concentration is reduced and there is a corresponding increase in strength.

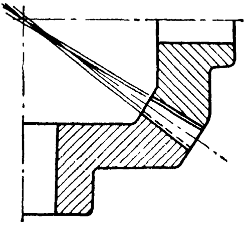

Fig. 14*a*.—According to the Revised System as Shown in the Above Axial Section, Face Cones of Blanks Are Turned *Parallel* to the Root Cone of the Mate in Order to Eliminate Possible Fillet Interference at the Small Ends of the Teeth.

Tooth Thicknesses.—The system is designed to provide gear and pinion teeth of approximately equal strength.

In determining tooth thickness to balance the strength of gear and pinion teeth, the load is taken in the position where it is carried entirely on one tooth.

PROPORTIONS OF SYSTEM

Dimensions in Inches

The following data are for straight bevel gears with generated teeth, with axes at right angles, and with thirteen or more pinion teeth; also, for general industrial drives, both speed-decreasing and speed-increasing.

TABLE 15*a*.—WORKING DEPTH AND WHOLE DEPTH

	Large and Medium Pitches, up to 20 D. P.	Fine Pitches, 20 D. P. and Finer
Working Depth	$\frac{2.000}{\text{D. P.}}$	$\frac{2.000}{\text{D. P.}}$
Whole Depth	$\frac{2.188}{\text{D. P.}}$	$\frac{2.250}{\text{D. P.}}$

TABLE 15*b*.—PRESSURE ANGLE[1]

14½ Degree Pressure Angle, Ratios with 27 or More Teeth in Pinion	17½ Degree Pressure Angle, Ratios	20 Degree Pressure Angle, Ratios
$\frac{26}{30}$ and higher $\frac{25}{35}$ and higher $\frac{24}{48}$ and higher	$\frac{26}{26}$ to $\frac{26}{29}$ $\frac{25}{25}$ to $\frac{25}{34}$ $\frac{24}{24}$ to $\frac{24}{47}$ $\frac{23}{23}$ to $\frac{23}{100}$ $\frac{22}{22}$ to $\frac{22}{100}$ $\frac{21}{21}$ to $\frac{21}{100}$ $\frac{20}{20}$ to $\frac{20}{100}$ $\frac{19}{19}$ to $\frac{19}{100}$ $\frac{18}{21}$ to $\frac{18}{100}$ $\frac{17}{26}$ to $\frac{17}{100}$	$\frac{18}{18}$ to $\frac{18}{20}$ $\frac{17}{17}$ to $\frac{17}{25}$ $\frac{16}{16}$ to $\frac{16}{100}$ $\frac{15}{15}$ to $\frac{15}{100}$ $\frac{14}{16}$ to $\frac{14}{100}$ $\frac{13}{28}$ to $\frac{13}{100}$

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[1] *All* ratios for aircraft and instrument gears.

TABLE 15*c*.—GEAR ADDENDUM[1] FOR 1 DIAMETRAL PITCH

Ratios		Add.	Ratios		Add.	Ratios		Add.	Ratios		Add.
From	To		From	To		From	To		From	To	
1.00	1.00	1.000	1.15	1.17	0.880	1.42	1.45	0.760	2.06	2.16	0.640
1.00	1.02	0.990	1.17	1.19	0.870	1.45	1.48	0.750	2.16	2.27	0.630
1.02	1.03	0.980	1.19	1.21	0.860	1.48	1.52	0.740	2.27	2.41	0.620
1.03	1.04	0.970	1.21	1.23	0.850	1.52	1.56	0.730	2.41	2.58	0.610
1.04	1.05	0.960	1.23	1.25	0.840	1.56	1.60	0.720	2.58	2.78	0.600
1.05	1.06	0.950	1.25	1.27	0.830	1.60	1.65	0.710	2.78	3.05	0.590
1.06	1.08	0.940	1.27	1.29	0.820	1.65	1.70	0.700	3.05	3.41	0.580
1.08	1.09	0.930	1.29	1.31	0.810	1.70	1.76	0.690	3.41	3.94	0.570
1.09	1.11	0.920	1.31	1.33	0.800	1.76	1.82	0.680	3.94	4.82	0.560
1.11	1.12	0.910	1.33	1.36	0.790	1.82	1.89	0.670	4.82	6.81	0.550
1.12	1.14	0.900	1.36	1.39	0.780	1.89	1.97	0.660	6.81	∞	0.540
1.14	1.15	0.890	1.39	1.42	0.770	1.97	2.06	0.650			

[1] To obtain addendum, select from table value corresponding to ratio given by the formula:

$$\text{Ratio} = \frac{\text{Number of teeth in gear}}{\text{Number of teeth in pinion}}$$

In case of choice, use the larger addendum

TABLE 15*d*.—CIRCULAR THICKNESS OF GEAR

Pressure Angle	Circular Thickness of Gear
$14\frac{1}{2}°$	$\frac{1.071}{\text{D. P.}} + (0.5 \times \text{addendum of gear}) - \frac{K\ (\text{Table 15}e)}{\text{D. P}}$
$17\frac{1}{2}°$	$\frac{0.971}{\text{D. P.}} + (0.6 \times \text{addendum of gear}) - \frac{K\ (\text{Table 15}c)}{\text{D. P.}}$
20°	$\frac{0.871}{\text{D. P.}} + (0.7 \times \text{addendum of gear}) - \frac{K\ (\text{Table 15}c)}{\text{D. P.}}$

TABLE 15*e*.—RECOMMENDED BACKLASH FOR GEARS ASSEMBLED READY TO RUN

D.P.[1]	BACKLASH
1	0.020 to 0.030
2	0.012 to 0.016
3	0.008 to 0.011
4	0.006 to 0.008
6	0.004 to 0.006
10	0.002 to 0.004
20 and finer	0.001 to 0.003

[1] Backlash for pitches other than those listed may be obtained by interpolation.

TABLE 15*f*.—VALUES OF K[1] FOR CIRCULAR THICKNESS FORMULA
(In Inches)

Number of Teeth in Pinion	Ratios														
	1.00 to 1.25	1.25 to 1.50	1.50 to 1.75	1.75 to 2.00	2.00 to 2.25	2.25 to 2.50	2.50 to 2.75	2.75 to 3.00	3.00 to 3.25	3.25 to 3.50	3.50 to 3.75	3.75 to 4.00	4.00 to 4.50	4.50 to 5.00	5.00 and Higher
13	0.000	0.015	0.040	0.045	0.050	0.060	0.070	0.080	0.090	0.100	0.110	0.120	0.135	0.150	0.165
14	0.000	0.015	0.030	0.050	0.065	0.080	0.090	0.100	0.110	0.120	0.125	0.130	0.140	0.150	0.160
15 to 17	0.000	0.000	0.010	0.020	0.030	0.045	0.060	0.070	0.080	0.090	0.095	0.100	0.110	0.115	0.120
18 to 21	0.000	0.000	0.000	0.000	0.010	0.030	0.045	0.060	0.070	0.080	0.085	0.090	0.095	0.100	0.100
22 to 29	0.000	0.000	0.000	0.000	0.010	0.030	0.040	0.050	0.060	0.065	0.070	0.070	0.080	0.085	0.085
30 and up	0.000	0.000	0.000	0.000	0.010	0.025	0.035	0.040	0.045	0.050	0.055	0.060	0.065	0.070	0.070

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[1] Select value according to ratio and number of teeth in pinion. In case of choice, use smaller value.

CALCULATIONS FOR STRAIGHT BEVEL GEAR DIMENSIONS

The linear dimensions given in the tables are for 1 diametral pitch. Linear dimensions for other pitches are obtained by dividing by the given D. P. *Angular dimensions remain the same for all pitches.*

To facilitate calculating the dimensions of straight bevel gears, formulas and calculations should be recorded on a form sheet such as shown in Table 15*g*, page 266*f*. The example calculated on the form sheet is for a pair of right-angle bevel gears, 16 × 49 combination, 5 D. P.

Remarks referring to certain of the calculations by number are given below. Figures 12 and 14*c* show, respectively, axial and transverse sections of a pair of bevel gears with the nomenclature and symbols used on the dimension sheet.

The following numbers refer to calculations on the form sheet:

4. **Face Width.**—It is strongly recommended that the face width of bevel gears should not exceed one-third of the cone distance. In best design, the ratio of face width to cone distance will be from 0.25 to 0.3. Increasing the face width over recommended proportions by adding to the small ends of the teeth theoretically adds strength and durability, but at a rapidly diminishing rate. Such practice results in manufacturing difficulties by requiring tools of less point width and *decreases possible fillet radii.* It may even increase the danger of breakage and wear if the load becomes concentrated on the small ends of the teeth.

6. **Whole Depth.**—It is recommended that gears of 10 D. P. and coarser be roughed 0.005 inch deeper than the calculated whole depth so that finishing tools will not cut on their ends. The calculated whole depth is, of course, used in subsequent calculations.

17. **Gage Angle.**—The "face angle gage" frequently employed in checking cone distance in generating machines requires setting the machine to the conventional face angle which corresponds to the addendum at the outer ends of teeth. The old, conventional face angle is therefore recorded as the "gage angle" for this purpose. If there are any who prefer to continue the previous practice in designing bevel gear blanks, this gage angle may be used as the face angle.

22. **Backlash.**—Table 15*e* gives the backlash when the gear and pinion are finished and assembled ready to run. Because of manufacturing tolerances and changes caused by heat treatment it may be necessary in cutting the teeth to allow for more than one-half the tabular value in order to obtain the desired backlash in assembly.

25. **Tooth Angle.**—The tooth angle is a machine setting in Gleason two-tool straight bevel gear generators. As shown in Fig. 14*b*, it is the angle at the machine center between the line to the center of the tooth and the line to the point of the tool.

26. **Limit Point Width.**—The limit point width is the point width of a straight-sided V tool of given pressure angle which will touch both sides and the bottom of a finished tooth space at the small end. The point width of the tools used must, of course, not be larger than the limit point width.

TABLE 15g.—STRAIGHT BEVEL GEAR DIMENSIONS
(Dimensions in inches)

1. Number of pinion teeth, n = 16
2. Number of geat teeth, N = 49
3. Diametral pitch, P = 5
4. Face width, F = 1.5
5. Working depth, h_k (Table 15*a*) = 0.400
6. Whole depth, h_t (Table 15*a*) = 0.438
7. Pressure angle, ϕ (Table 15*b*) = 20°

	Pinion		Gear	
8. Pitch diameter	$d = \frac{n}{P}$	3.2000	$D = \frac{N}{P}$	9.8000
9. Cone distance	$A_o = \frac{D}{2 \sin \Gamma}$		5.1546	
10. Circular pitch	$P = \frac{3.1416}{P}$		0.6283	
11. Addendum	$a_P = h_k - a_G$	0.284	$a_G = \frac{\text{Table 15}c}{P}$	0.116
12. Dedendum	$b_P = h_t - a_P$	0.154	$b_G = h_t - a_G$	0.322
13. Clearance	$C = h_t - h_k$		0.038	
14. Pitch angle	$\gamma = \tan^{-1} \frac{n}{N}$	18° 5′	$\Gamma = 90° - \gamma$	71° 55′
15. Dedendum angle	$\delta_P = \tan^{-1} \frac{b_P}{A_o}$	1° 42′	$\delta_G = \tan^{-1} \frac{b_G}{A_o}$	3° 34′
16. Face angle of blank	$\gamma_o = \gamma + \delta_G$	21° 39′	$\Gamma_v = \Gamma + \delta_P$	73° 37′

TABLE 15g.—STRAIGHT BEVEL GEAR DIMENSIONS.—*Continued*
(Dimensions in Inches)

	Pinion		Gear	
17. Gage angle	$\gamma_F = \gamma + \tan^{-1} \dfrac{a_P}{A_o}$	21° 14′	$\Gamma_F = \Gamma + \tan^{-1} \dfrac{a_G}{A_o}$	73° 12′
18. Root angle	$\gamma_R = \gamma - \delta_P$	16° 23′	$\Gamma_R = \Gamma - \delta_G$	68° 21′
19. Outside diameter	$d_o = d + 2a_P \cos \gamma$	3.740	$D_o = D + 2a_G \cos \Gamma$	9.872
20. Cone center to crown	$\dfrac{D}{2} - a_P \sin \gamma$	4.812	$\dfrac{d}{2} - a_G \sin \Gamma$	1.490
21. Circular thickness	$t = p - T$	0.3889	T (Table 15*d*)	0.2394
22. Backlash	(Table 15*f*)	0.006–0.008		
23. Chordal thickness	$t_C = t - \dfrac{t^3}{6d^2} - \dfrac{\text{Backlash}}{2}$	0.385	$T_C = T - \dfrac{T^3}{6D^2} - \dfrac{\text{backlash}}{2}$	0.236
24. Chordal addendum	$a_{PC} = a_P + \dfrac{t^2 \cos \gamma}{4d}$	0.295	$a_{GC} = a_G + \dfrac{T^2 \cos \Gamma}{4D}$	0.116
25. Tooth angle	$\dfrac{3438}{A_o}\left(\dfrac{t}{2} + b_P \tan \Phi\right)_{\text{Minutes}}$	2° 47′	$\dfrac{3438}{A_o}\left(\dfrac{T}{2} + b_G \tan \Phi\right)_{\text{Minutes}}$	2° 38′
26. Limit point width	$\dfrac{A_o - F}{A_o}(T - 2b_P \tan \Phi)$	0.090	$\dfrac{A_o - F}{A_o}(t - 2b_G \tan \Phi)$	0.110

NOTE.—The first letters or symbols in both Pinion and Gear columns represent the dimensions in the first column for Pinion and Gear, *i.e.*, A_o = cone distance on both pinion and gear, which are the same. In the same way γ_F and Γ_F = gage angle for pinion and for its mating gear.

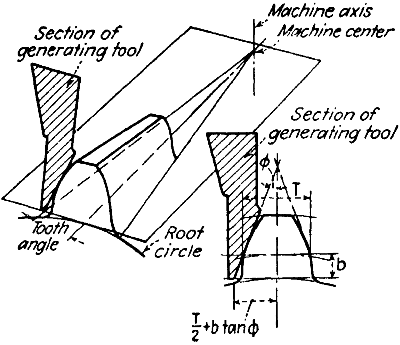

FIG. 14*b*.—The Tooth Angle Is the Angle at the Machine Center between the Line to the Center of the Tooth and the Line to the Point of the Tool.

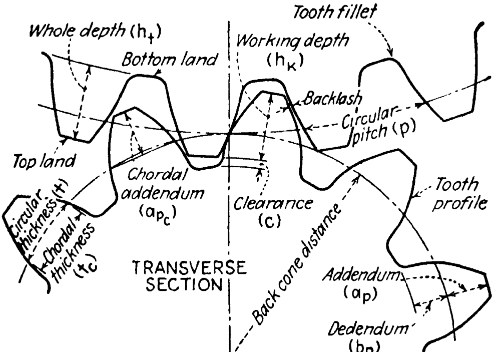

FIG. 14*c*.—Bevel Gear Nomenclature and Symbols.

FORM SHEET DATA FOR ANGULAR STRAIGHT BEVEL GEARS

Angular bevel gears are bevel gears whose shafts operate at angles other than 90 degrees. The formulas in Table 15*g* are not directly applicable in calculating the dimensions of angular gears. Therefore, a summary of procedure for angular gears is outlined below in order of calculation, with the item numbers referring to the items in Table 15*g*.

Using item numbers 1, 2, 3, 4, which are given, calculate items 5, 6, 8, 10, 13 from the formulas given.

14. Pitch Angles.—Case I—Shaft Angle (Σ) less than 90 degrees.

$$\tan \Gamma = \frac{\sin \Sigma}{\frac{n}{N} + \cos \Sigma}; \qquad \tan \gamma = \frac{\sin \Sigma}{\frac{N}{n} + \cos \Sigma}$$

Case II—Shaft Angle (Σ) greater than 90 degrees. The formulas given below will apply only if the pitch angle Γ is less than 90 degrees. If Γ is greater than 90 degrees (internal gear) calculations should be referred to the Gleason Works.

$$\tan \Gamma = \frac{\sin (180^\circ - \Sigma)}{\frac{n}{N} - \cos (180^\circ - \Sigma)};$$

$$\tan \gamma = \frac{\sin (180^\circ - \Sigma)}{\frac{N}{n} - \cos (180^\circ - \Sigma)}$$

In either case above

$$\Sigma \text{ (shaft angle)} = \Gamma + \gamma$$

9. . . . Formulas same as given.

11. Determination of the *tooth proportions* necessitates computing the equivalent 90° bevel gear ratio.

$$\text{Equivalent } 90^\circ \text{ ratio } \frac{N_{90}}{n_{90}} = \sqrt{\frac{N \cos \gamma}{n \cos \Gamma}} = \tan \Gamma_{90}$$

The value so computed should be used as the ratio when determining the gear addendum for 1 diametral pitch in Table 15*c*.

11, 12. . . . Formulas same as given. (See explanation in preceding paragraph for item 11.)

15, 16, 17, 18, 19. . . . Formulas same as given.

20. Cone Center to Crown

$$\text{Pinion} = A_o \cos \gamma - a_P \sin \gamma$$
$$\text{Gear} = A_o \cos \Gamma - a_G \sin \Gamma$$

7. Pressure Angle.—The pressure angle for angular gears should not be taken from Table 15*b*. The calculated minimum pressure angle (Φ') is given by the formula:

$$\sin \Phi' = \sqrt{\frac{b_P}{A_o \tan \gamma}}$$

The selected pressure angle Φ in item 7 should be made equal to or greater than Φ'. Use either of the standard angles—14 degrees 30 minutes, 17 degrees 30 minutes, or 20 degrees. When Φ' is greater than 20 degrees, the job requires special consideration.

21. . . . Formula same as given. However, the *value of K* in Table 15*d* must be determined using the number of teeth in the equivalent 90 degree bevel pinion and the equivalent 90 degree bevel ratio. The latter is computed above (item 11).

Number of teeth in equivalent 90 degree bevel pinion

$$n_{90} = \frac{n \sin \Gamma_{90}}{\cos \gamma}$$

$$(\tan \Gamma_{90} = \text{equivalent } 90^\circ \text{ ratio})$$

22, 23, 24, 25, 26. . . . Formulas same as given.

Angular gears require special *ratio of roll gears* for generating on the Gleason generators. The decimal ratio for the ratio gears is found by the following formula:

$$\text{Decimal ratio of gears} = \frac{A_o P}{37.5}$$

The work roll is found in the usual manner from the decimal ratio.

THE HOBBING METHOD OF CUTTING GEAR TEETH[1]

Hobbing is a machine process for generating gear teeth. All methods of cutting gear teeth fall into either one of two general classes—the forming method or the generating method. In the forming method, the tool is given a shape matching that of the desired tooth space; in the generating method, the tool has a shape conjugate to the form of the tooth when rolled in contact with it and frequently can be substantially straight, as in hobbing.

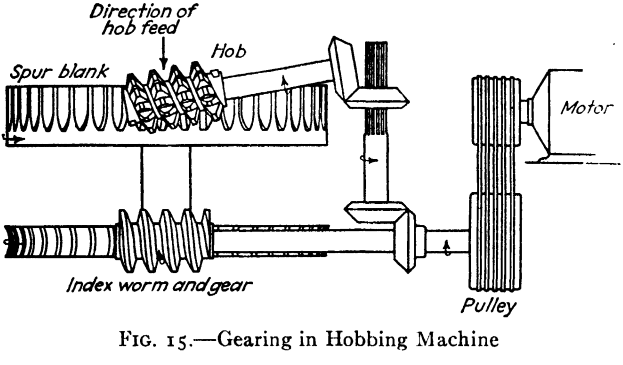

FIG. 15.—Gearing in Hobbing Machine

The cutter in the hobbing process is called a "hob." The nature of a hob may be best understood by comparing it with a worm as shown in Fig. 15. In making a hob, a cylindrical blank is first turned and bored, then the helical thread resembling a worm thread is milled; in this state the hob is actually a worm. The cutting teeth are produced by milling gashes across the thread, either parallel to the hob axis or at right angles to the thread. The sides and tops of the individual hob teeth are relieved to provide cutting clearances similar to milling cutters. After the hardening operation, the hole, proof diameters, and the sides and tops of the teeth are all ground. The hob is sharpened by grinding the gashes.

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[1] By Granger Davenport, Assistant Engineer, Gould and Eberhardt, Irvington, N.J.

A hob and blank being cut may be likened to a worm and worm gear in mesh as in Fig. 15. Hobbing is a continuous milling process in which the hob and blank both rotate in timed relation to each other. In addition to the rotary motion, the hob and gear blank are fed relatively to each other to produce the spur, helical, or worm gear. In the hobbing process the cutting action is continuous in one direction until the blank is finished. Modern hobbing machines have a high degree of accuracy built in that can be maintained over a long period of years by adjusting means incorporated therein. Hobbing is, therefore, widely used for cutting precision gears at a high rate of production.

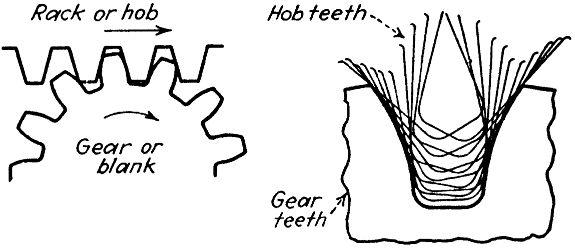

FIG. 16.—How Teeth Are Generated

The hob for spur or helical gears is provided with a tooth form identical with that of an involute helical gear having only one tooth. This tooth form is theoretically curved to mesh properly with the curved involutes generated on the blank. However, the hob form so nearly approaches a straight-line rack-tooth shape that the difference is extremely slight. This is a fundamental advantage of the hobbing process, because hob teeth being straight-sided, or nearly so, are readily made to a very high degree of accuracy and are easily measured, as compared to curved cutter teeth used in some methods of gear cutting.

Sections through a hob and gear blank at right angles to a pair of teeth in contact are represented in Fig. 16. The teeth in the hob section actually form the path of an ellipse, but, practically speaking, they are equivalent to a rack, because the degree of curvature of the ellipse within the arc of tooth contact is almost nil.

Figure 16 also illustrates how successive hob teeth coming into contact with each tooth in the blank, generate gear teeth of involute form. Hobbing is not limited to the involute form, although for spur and helical gears this form is used almost exclusively at the present time. In the involute system a straight-sided rack will mesh properly with a gear or pinion regardless of the number of teeth. Consequently, one hob can be used to generate gears of any number of teeth, all of which will mesh properly with each other and with a rack.

Angular Setting of the Hob

The axis of the hob for cutting spur gears is tilted according to the hob thread angle to have the hob teeth in line with the teeth of the blank, as in Fig. 17. In cutting helical gears, the hob is tilted an additional amount so that the teeth coincide with the inclination of the teeth being produced on the blank, also illustrated in Fig. 17. In this case the angle of tilt equals the helix angle of the gear minus the thread angle of the hob, when both are of the same hand. When they are of opposite hands, the angle of tilt is the sum of the two angles.

A slight variation in setting the hob angle of tilt affects neither the tooth form nor the helix angle. An angular error of as much as several minutes can be tolerated with no noticeable effect on the product other than slightly thinner teeth and increased backlash. This is an inherent advantage of the hobbing method.

The Gearing in a Hobbing Machine

The arrangement of a hobbing machine may be readily understood by referring to the simplified gearing diagram shown in Fig. 15. The driving pulley uniformly rotates the blank through a master dividing worm and gear, commonly termed the "index" worm and gear. The four bevel gears connected to the same pulley shaft rotate the hob at a definite relative speed. Thus the hob and blank are synchronized through gearing. As the hob is fed downward, parallel to the axis of the blank, by a feed screw (not shown), one bevel gear slides along the vertical splined shaft.

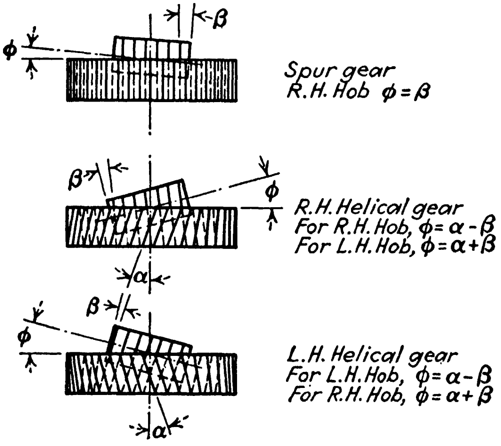

FIG. 17.—Angular Setting for Hobbing

Ordinarily, a machine simplified to the extent shown is obviously impractical unless limited to one number of teeth. By introducing change gears in the drive to the index worm, the relative ratio of rotation between the blank and hob may be changed to cut any number of teeth desired. To cut spur and helical gears of various pitches, additional mechanism must be introduced in the hob drive to permit tilting to the required angle. A feed screw and related mechanism driven from the index worm shaft feed the hob at a definite rate with respect to the rotation of the blank. Suitable change gearing is employed to vary the feed.

The hob speed is changed to suit the cutting conditions by varying the speed of the main drive shaft. This also is accomplished by change gears, which, in this case, alter the speed of the entire mechanism proportionately. For instance, if the speed of the hob is doubled, it is obvious from Fig. 15 that the speeds of the blank and feed are increased to the same extent and the production is doubled.

Hobbing Spur Gears

The first step in the preparation for cutting a gear is to mount a fixture on the work table or spindle. Second, a blank is accurately clamped to the fixture and indicated for running true. The hob is then clamped upon its arbor and tilted to the correct angle. Next, the proper change gears are selected and placed upon the machine according to the number of teeth to be cut and for the hob speed and feed required.

The ratio of the index change gears depends upon the total ratio of the index and cutter gear trains. For example, if the machine ratio is 30, then the index formula is $\frac{30T}{N}$, in which N equals the number to be cut and T equals the number of threads in the hob. Usually a chart is provided showing index change-gear combinations for a selected range of teeth. In other cases, the formula is applied by substituting values for N and T, and splitting the result into two fractions suitable for change gears. The calculations must be exact.

Next the feed change gears are selected from the chart or calculated by the feed formula. These change gears may be approximate. In a similar manner, the hob-speed change gears are selected from the chart.

The machine is then started and the feed engaged. After the hob has fed across the face of the gear, the cutting is completed and the gear is removed or the hob is returned to its initial position for a finishing cut.

Hobbing Helical Gears—Non-Differential Method

In hobbing helical gears non-differentially, the same fundamental type of machine described for spur gears is used.

In this method the index and feed change gearing are so calculated that the blank and cutter are advanced or retarded slightly with respect to each other to produce the helix angle. The increase or decrease in relative rotation must be definitely correlated with the feed selected. Consequently, in both the index and feed formulas a factor, in the form of a constant, is introduced. The calculation of this constant may be very approximate, as long as the same value is used in both index and feed formulas. The index change gearing must be exact, as in spur-gear cutting, whereas the feed change-gear calculations should be carried to the fourth or fifth decimal place depending upon how close it is desired to approximate the theoretical helix angle. It is unnecessary to describe this method further because instructions are furnished with each hobbing machine and should be consulted for details.

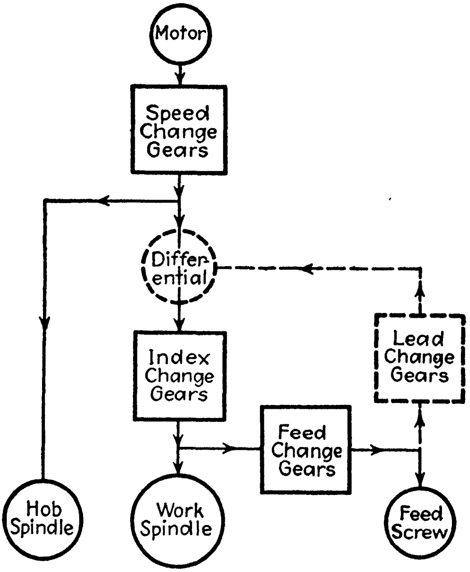

FIG. 18.—Diagram of Hobbing Machine Layout

Hobbing Helical Gears—Differential Method

In the differential method, additional mechanism is required to obtain the increase or decrease of the relative rotation of the hob and blank to produce the helix angle. This mechanism usually comprises a bevel-gear type of differential connected to affect the rotation of the blank and correlated to the feed motion through an extra set of change gears for the lead. The differential functions by imparting a supplemental motion to the existing direct drive to the work table.

A schematic diagram of a hobbing machine, including a differential and lead gears, is shown in Fig. 18. The differential and lead gears are shown in dotted lines to indicate the mechanism added to a non-differential machine for cutting helical gears by the differential method. The power originating at the motor passes through speed change gears and branches to the hob and work spindles. The differential and index change gears are located in the branch drive to the work spindle. A branch to the feed screw is taken off between the index change gears and work spindle. The feed change gears are provided in this branch line, and drive both the feed screw and the differential. The lead change gears are located in the drive to the differential.

In the differential method the index change gears are selected from a chart, the same as for spur gears. The feed change gears are also selected directly from a chart. The rate of feed can be changed at will without affecting the index or lead gearing, resulting in a greater flexibility in this respect than the non-differential method. The lead change gears connecting the feed to the differential determine the helix angle. Therefore, the lead change-gear calculations must be correct to the same degree of accuracy as for *feed* change gears in non-differential hobbing in order to approximate the theoretical helix angle.

Differential versus Non-Differential Hobbing

When a helical gear is cut differentially and a second cut is required, it is merely necessary to disconnect the feed, move the cutter slide to the initial position, and proceed with the recut. In other words, the relation of the hob to the teeth of the blank being cut is always automatically maintained, as when recutting a spur gear.

On the other hand, if a gear has been cut non-differentially and the feed is disconnected for the purpose of returning the slide to the initial position, the lead relation of the hob teeth to the blank teeth is destroyed, making it necessary to reset the cutter and blank very carefully to have the second cut clean up evenly on both sides. If there is a reasonable amount of stock left on the teeth for the finishing cut, this operation is comparatively simple. But if the finishing cut is to remove very little stock, the proper setting of the cutter becomes quite difficult. Various devices are employed to aid in resetting the hob for the second cut on non-differential machines. One is a clutch arranged to temporarily disengage the feed-screw drive until the hob teeth are seen to track exactly in the gear-tooth spaces. Another comprises a clutch in the index-worm drive and a set of three pointers and zero marks, enabling the work table, cutter spindle, and cutter slide, to be returned to their initial zero positions for the recut. However, none of these methods is as reliable as the differential method for very light recuts. Thus, it is evident that while a differential complicates the mechanism, it is valuable if helical gears are to be hobbed in more than one cut.

There are still other advantages of the differential method. For instance, if mating gears are to be cut on the same machine or with the same lead change gearing, a considerable departure from the theoretical helix angle may be tolerated. Under these circumstances the change-gear calculations need not be carried out to the high degree of accuracy required for non-differential hobbing of helical gears. However, if pinion and gear are cut on different machines with unlike lead formulas, these approximate calculations will not suffice, and the same accuracy is required as for non-differential feed gear calculations.

The non-differential machine is simpler and less expensive than one equipped with a differential. This is an important consideration for mass-production shops.

Other advantages of the non-differential method are for certain combinations of pitch and helix angle beyond the range of a differential machine and for helical gears with large prime numbers of teeth. In special cases, it is possible to cut non-differentially and to engage the differential only while returning the slide for the recut, thus maintaining the lead relation.

In general, to obtain the benefits of both differential and non-differential hobbing, the machine should be equipped with a differential, which may be locked or disengaged when not needed.

Hobs for Spur and Helical Gears

The same hob used for spur gears is suitable for cutting helical gears of either hand and of any helix angle. If the helix angle is more than 10 or 12 degrees and the quantity of helical gears to be cut is large, it will be found advantageous to use two hobs, the hand of each corresponding to the hand of the gear being cut. When the helix angle is more than 20 or 25 degrees, it is preferable to taper the hob to relieve the load on the end teeth.

For small lots, the same hob is used for both roughing and finishing. For medium or large lots, it is more economical to rough with an unground or rough-ground hob and to finish with a ground hob. A ground hob is one having the sides and tops of its teeth ground after hardening. Under no circumstances should unground hobs be used for finishing either spur or helical gears, because the inaccuracies resulting from hob distortion in heat-treatment will seriously affect the tooth forms of the gears.

Unless otherwise specified, finishing hobs are given a slight modification in form for producing tip relief on the gear teeth. This eases the gears into mesh and helps to quiet the gears during their initial running-in period.

One of the most important factors in the use of hobs is proper sharpening. In sharpening, it is essential to mount the hobs on arbors running exactly true, to maintain exact spacing of the gashes, and to maintain the faces of the teeth exactly radial or to the original hook angle. If hobs are properly sharpened, their initial accuracy of lead and form will remain throughout their life.

In mounting hobs on the hobbing machine, they must run true within 0.00025 inch (a quarter of a thousandth) indicator reading at each end, otherwise inaccurate tooth forms and noisy gears will result.

The cutting action of a hob is distributed over many teeth, producing a large number of tooth inches before sharpening is required. When a hob shows signs of becoming dull, it should be shifted axially about one linear pitch to utilize sharp teeth in a new zone; this should be repeated until the entire hob is dull, before sharpening. The special tapered-end hobs for high-angle helical gears cannot be shifted in this manner, hence they are made much shorter than standard spur-gear hobs and require more frequent sharpening.

Multiple-thread hobs should be used for roughing to save time. The cutting action of these roughing hobs is improved by having the teeth undercut or hooked, instead of radially gashed.

Shear-type roughing hobs are particularly advantageous in cutting the higher carbon steels at fast feeds and speeds. The shearing action is obtained by making the hand of gash opposite to the hand of the thread, and hooking the teeth. In this type of hob the lead is modified to distribute the cutting action among more cutting teeth; this, however, restricts the range of teeth that may be cut by any one shear-cut hob.

Speeds and Feeds for Spur Gears

The speeds for cast iron vary from 40 to 100 feet per minute usually being about 80. For steel, the speed varies from 60 to 150 feet per minute, averaging approximately 100.

The feed per revolution of blank is ordinarily 0.030 to 0.050 inch for a single-cut job. For roughing, it ranges from 0.060 to 0.200 inch with special roughing hobs. For double-thread roughing hobs, the feed is reduced about one-third, and the index gearing is arranged for half the number of teeth, almost doubling the production. In finishing after roughing cuts, the feed ranges from 0.040 to 0.060 inch according to the finish desired.

Speeds and Feeds for Helical Gears

The speeds for hobbing helical gears are the same as for spur gears. The feeds per revolution of blank given for spur gears should be reduced as the helix angle increases, to maintain the same quality of finish. In selecting a feed for a helical gear, the appropriate spur-gear feed is multiplied by the cosine of the helix angle.

Coolant

Sulphurized mineral oil in combination with lard oil is preferable for hobbing steel to attain maximum cutter life, improved finish, equalized temperature, and maximum production. Soluble oil in water in sometimes used, but this is better suited for bronze and brass. No coolant is necessary for cast iron.

Hobbing Worm Gears—Infeed Method

Worm gears may be produced by the infeed method. The hob is fed in a radial direction toward the center of the blank instead of across the face of the blank as in spur-gear hobbing. When the proper center distance has been reached, as indicated by a scale and vernier on the machine, the feed is disengaged and the blank permitted to rotate at least one extra revolution until the hob stops cutting and the operation is completed.

The index change gears for the infeed method are the same as for spur gears. The feed change gears may be approximate and are selected from a chart.

The hob is usually set at exactly right angles to the axis of the worm-gear blank. Sometimes the hob is tilted angularly when either over- or undersized, to compensate for the slight change in thread angle. In any case, the angular setting of the hob arbor must be accurate if cross-cornered tooth contact is to be avoided; this is an important difference in set-up as compared to spur or helical gear hobbing.

An infeed hob should be an exact duplicate in tooth form and lead of the worm that is to mesh with the gear, except that the tooth height is increased for clearance and the tooth thickness increased for the necessary backlash.

Infeeding is only suitable when the thread angle of the worm does not exceed 6 or 7 degrees. On larger angles, infeeding destroys part of the useful tooth surfaces, and the tangential method is therefore preferable.

Hobbing Worm Gears—Tangential Method

In hobbing worm gears tangentially, the direction of feed is along a line tangent to the blank and parallel with the axis of the hob. In this method the hob is set at the exact center distance and to one side of the center line to clear the blank entirely. The gear teeth are first roughed out by the leading end of the hob and finish cut as the hob passes through the blank. The index change gears and angular setting of the hob are the same as in infeeding.

Feeding the hob tangentially requires a supplemental rotative motion to the blank to synchronize the relation between the teeth of the hob and the blank. This is accomplished by a differential and lead change gearing calculated from the lead of the job. These calculations must be very accurate.

The tangential method is inherently much slower than the infeed method; hence, it is common practice to precede the tangential cut by a roughing infeed cut to save time. For this combined cutting, separate hobs may be used, mounted on the same arbor, or one hob may serve both operations.

Hobs for Worm Gears

Infeed hobs are cylindrical in shape and in general appearance resemble spur-gear hobs.

Hobs for tangential feeding usually have the teeth at the entering end tapered in width and height to divide the load among several teeth and ease the cutting action.

Roughing hobs and the roughing teeth on finishing hobs may be unground, but the finishing teeth or tooth should always be ground if satisfactory tooth forms are to be produced.

Hobs of small diameters and coarse pitches are made with solid shanks to avoid small cutter arbors. This condition frequently occurs because, from a design standpoint, worms are made relatively small in diameter. Small worm diameters result in steep thread angles and consequently high worm and gear efficiency.

Fly tools tangentially fed provide a means to cut a single gear or limited quantities without an expensive hob. The fly tool consists of a single finishing hob tooth clamped in the cutter arbor and fed across the blank like a tangential hob but at a very much reduced rate of feed.

The tooth forms of worm-gear hobs and fly tools may be involute or straight sided in an axial or normal plane, or they may be given special shapes conjugate to straight-sided milling cutters or grinding wheels of definite diameters. The choice of form depends upon the equipment available for making the worms.

The successful operation of a worm and gear depends a great deal upon the care exercised in the shop to produce good contact between the worm and worm-gear teeth. Proper tooth contact is dependent particularly upon the precision of the worm, also upon the condition and setup of the hobbing machine and the accuracy of the worm-gear hob. The precautions in handling hobs, as outlined under spur and helical gears, are equally important for worm gears.

Other Applications of the Hobbing Method

Hobbing is by no means limited to the three general types of gears mentioned. It is also widely used for double helical or herringbone gears, helical gears for operation on crossed axes (sometimes termed "spiral gears"), pump rotors, single- and multiple-threaded worms, sprockets, ratchet gears, straight-sided and involute splines, etc. Special worms and gears, such as the Hindley, hour-glass, and Cone types, are also manufactured on hobbing machines.

TABLE 16.—ACCURACY REQUIRED OF CHANGE-GEAR COMBINATIONS ON HOBBING MACHINES

Types of Gears Being Hobbed	Change Gearing			
	Index	Feed	Lead	Speed
Spur gears.	Exact, from chart	Approximate, from chart	....	Approximate, from chart
Helical gears cut with differential.	Exact, from chart	Approximate, from chart	Accurate as possible; *approximate	Approximate, from chart
Helical gears cut non-differentially.	Exact	Accurate as possible	....	Approximate, from chart
Worm gears cut with infeed.	Exact, from chart	Approximate, from chart	....	Approximate, from chart
Worm gears cut with tangential feed.	Exact, sometimes from chart	Approximate, from chart	Accurate as possible	Approximate, from chart

* Permissible only when same lead gearing is used for cutting both pinion and gear.

The Barber-Colman Company, which specializes in fine-pitch hobs, suggests the following:

Table 16a.—Barber-Colman Standard Fine Pitch Hob Sizes
(Dimensions in Inches)

D. P.	Bore	Diameter	Length
30 to 54	0.2362 (6 mm.)	⅝	½
	0.315 (8 mm.)	¾—⅞—1	½
	0.3937 (10 mm.)	1	½
	0.500	1⅛	1⅛
	0.750	1⅞	1½
55 to 84	0.2362 (6 mm.)	⅝	½
	0.315 (8 mm.)	¾—⅞—1	½
	0.3937 (10 mm.)	1	½
	0.500	1⅛	1⅛
	0.750	1⅝	1½
85 to 129	0.2362 (6 mm.)	⅝	½
	0.315 (8 mm.)	¾—⅞—1	½
	0.3937 (10 mm.)	1	½
	0.500	1⅛	⅞
	0.750	1½	¾
130 to 200	0.2362 (6 mm.)	⅝	½
	0.315 (8 mm.)	¾—⅞—1	½
	0.3937 (10 mm.)	1	½
	0.500	1⅛	½
	0.750	1⅜	⅝

FINE PITCH HOBS

Size

In manufacturing fine pitch hobs, size characteristics are determined by the type and size of the machine on which they are to be used. Diameter and face are held as small as possible so that the number of teeth in the hob may be consistent with manufacturing operations required, and at the same time give desired finish on profile. If a hob is too large in diameter or too wide in cutting face the accuracy of the form cannot be maintained across the entire width because the forming tool or the grinding wheel would have to be reconditioned before this distance is completed. For example, there are approximately 230 teeth on a 200 D.P., ¾-inch-diameter, ½-inch-long ground hob. If the diameter or length were increased, it would add to difficulty in manufacturing.

The fact that the pitch on these hobs is so fine actually provides a multiplicity of settings. Each setting requires only a slight shift in the position of the hob, depending on pitch and number of teeth in the work. There is, therefore, no necessity for a wide face hob. Unground hobs should not exceed approximately 300 cutting teeth ground hobs, 250 teeth, allowing for fewer gashes.

Ground hobs are furnished up to 200 D. P. depending on the form; unground hobs up to 250 D. P.

Importance of Frequent Hob Shifting

Hobs should be shifted frequently and in short amounts in order to obtain the best possible cutting conditions and longest hob life. After a hob has been used in one position for any length of time, the operator can tell how many teeth have been in use and how much wear each one shows. From the amount of wear, the operator can calculate the distance the hob should be shifted to get maximum life and uniform wear from all teeth. Many shops establish a maximum amount of wear to be permitted, and when the hob reaches this point it should be shifted to another position. A *right* hand hob, *top coming*, should always be shifted to the *right;* a *left* hand hob to the *left*.

All teeth used will not show the same amount of wear. Select a tooth around the lead which shows maximum wear. Consider this wear in terms of amount of stock which has to be removed to restore the hob to a good keen cutting edge. This should not exceed 0.003 inch to 0.006 inch, depending on the pitch and accuracy of profile. Shift the hob far enough so that the tooth with maximum wear will clear the cut. It is not necessary to shift so far that all teeth used will clear in the new position; those showing minimum wear may be used again cutting in a different position.

To set the hob properly be sure that either one hob tooth or one tooth space is centered on the center line of the gear blank. This position will produce symmetrical generating flats, and is usually accomplished by trial moving the hob endwise until a symmetrical form has been obtained, or with the aid of a gage. After this position has been obtained the hob should be shifted *one full circular pitch* each time. This is important and should be carefully observed if good pinions are to be obtained.

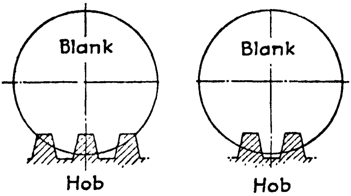

TABLE 16b.—SMALL DIAMETER GEAR HOB LIMIT CHART

		30 to 50 Pitch	51 Pitch and Finer
Hob Runout			
Face within	Class A	0.0001	0.0001
	Class B	0.0002	0.0002
	Unground	0.0003	0.0002
O.D. within	Class A	0.0001	0.0001
	Class B	0.0002	0.0002
	Unground	0.0004	0.0002
Runout of O.D.	Class A	0.0007	0.0005
	Class B	0.0007	0.0005
	Unground	0.0015	0.0010
Sharpening			
Indexing flute to flute	Class A	0.001	0.0010
	Class B	0.001	0.0010
	Unground	0.0017	0.0017
Accumulated error in one revolution must not exceed	Class A	0.002	0.0015
	Class B	0.0025	0.002
	Unground	0.040	0.003
Radialism for depth of form	Class A	0.0003	0.0003
	Class B	0.0005	0.0005
	Unground	0.001	0.001
Thread			
Lead variation in one complete turn must not exceed	Class A	0.0003	0.0003
	Class B	0.0004	0.0003
	Unground	0.001	0.0007
Tooth to tooth	Class A	0.0002	0.0002
	Class B	0.0002	0.0002
	Unground	0.0005	0.0004
Three turns	Class A	0.0005	0.0005
	Class B	0.0007	0.0005
	Unground	0.001	0.001
Tooth Profile or Pressure Angle			
Must be symmetrical within (plus or minus)	Class A	0.0002	0.0003
	Class B	0.0003	0.0003
	Unground	0.0006	0.0006
Straight portion within (plus or minus)	Class A	0.0002	0.0002
	Class B	0.0002	0.0002
	Unground	0.0006	0.0005
Start of approach within (plus or minus)	Class A	0.002	
	Class B	0.003	
	Unground	0.004	
Symm. of approach within (plus or minus)	Class A	0.002	
	Class B	0.0025	
	Unground	0.004	
Tooth thickness	Class A	−0.001	−0.0005
	Class B	−0.001	−0.0005
	Unground	−0.001	−0.0005
Hole	Class A	+0.0002 −0.0000	+0.0002 −0.0000
	Class B	+0.0002 −0.0000	+0.0002 −0.0000
	Unground	+0.0003 −0.0000	+0.0003 −0.0000

TABLE 16*c*.—GEAR TOOTH PARTS
Fine Pitch Series
(A. G. M. A. recommended practice)

Diametral Pitch	Circular Pitch	Circular Thickness	Addendum	Dedendum	Working Depth	Whole Depth
30	0.10472	0.05236	0.0333	0.0420	0.0667	0.0753
31	0.10134	0.05067	0.0323	0.0407	0.0645	0.0730
32	0.09818	0.04909	0.0313	0.0395	0.0625	0.0708
33	0.09520	0.04760	0.0303	0.0384	0.0606	0.0687
34	0.09240	0.04620	0.0294	0.0373	0.0588	0.0667
35	0.08976	0.04488	0.0286	0.0363	0.0571	0.0649
36	0.08727	0.04363	0.0278	0.0353	0.0556	0.0631
37	0.08491	0.04245	0.0270	0.0344	0.0541	0.0615
38	0.08267	0.04134	0.0263	0.0336	0.0526	0.0599
39	0.08055	0.04028	0.0256	0.0328	0.0513	0.0584
40	0.07854	0.03927	0.0250	0.0320	0.0500	0.0570
41	0.07662	0.03831	0.0244	0.0313	0.0488	0.0557
42	0.07480	0.03740	0.0238	0.0306	0.0476	0.0544
43	0.07306	0.03653	0.0233	0.0299	0.0465	0.0532
44	0.07140	0.03570	0.0227	0.0293	0.0455	0.0520
45	0.06981	0.03491	0.0222	0.0287	0.0444	0.0509
46	0.06830	0.03415	0.0217	0.0281	0.0435	0.0498
47	0.06684	0.03342	0.0213	0.0275	0.0426	0.0488
48	0.06545	0.03272	0.0208	0.0270	0.0417	0.0478
49	0.06411	0.03206	0.0204	0.0265	0.0408	0.0469
50	0.06283	0.03142	0.0200	0.0260	0.0400	0.0460
51	0.06160	0.03080	0.0196	0.0255	0.0392	0.0451
52	0.06042	0.03021	0.0192	0.0251	0.0385	0.0443
53	0.05928	0.02964	0.0189	0.0246	0.0377	0.0435
54	0.05818	0.02909	0.0185	0.0242	0.0370	0.0427
55	0.05712	0.02856	0.0182	0.0238	0.0364	0.0420
56	0.05610	0.02805	0.0179	0.0234	0.0357	0.0413
57	0.05512	0.02756	0.0175	0.0231	0.0351	0.0406
58	0.05417	0.02708	0.0172	0.0227	0.0345	0.0399
59	0.05325	0.02662	0.0169	0.0223	0.0339	0.0393
60	0.05236	0.02618	0.0167	0.0220	0.0333	0.0387
61	0.05150	0.02575	0.0164	0.0217	0.0328	0.0381
62	0.05067	0.02534	0.0161	0.0214	0.0323	0.0375
63	0.04987	0.02493	0.0159	0.0210	0.0317	0.0369
64	0.04909	0.02454	0.0156	0.0208	0.0313	0.0364
65	0.04833	0.02417	0.0154	0.0205	0.0308	0.0358
66	0.04760	0.02380	0.0152	0.0202	0.0303	0.0353
67	0.04689	0.02344	0.0149	0.0199	0.0299	0.0348
68	0.04620	0.02310	0.0147	0.0196	0.0294	0.0344
69	0.04553	0.02277	0.0145	0.0194	0.0290	0.0339
70	0.04488	0.02244	0.0143	0.0191	0.0286	0.0334
71	0.04425	0.02212	0.0141	0.0189	0.0282	0.0330
72	0.04363	0.02182	0.0139	0.0187	0.0278	0.0326
73	0.04304	0.02152	0.0137	0.0184	0.0274	0.0321
74	0.04245	0.02123	0.0135	0.0182	0.0270	0.0317

TABLE 16*c*.—GEAR TOOTH PARTS.—*Continued*
Fine Pitch Series
(A. G. M. A. recommended practice)

Diametral Pitch	Circular Pitch	Circular Thickness	Addendum	Dedendum	Working Depth	Whole Depth
75	0.04189	0.02094	0.0133	0.0180	0.0267	0.0313
76	0.04134	0.02067	0.0132	0.0178	0.0263	0.0309
77	0.04080	0.02040	0.0130	0.0176	0.0260	0.0306
78	0.04028	0.02014	0.0128	0.0174	0.0256	0.0302
79	0.03977	0.01988	0.0127	0.0172	0.0253	0.0298
80	0.03927	0.01964	0.0125	0.0170	0.0250	0.0295
81	0.03879	0.01939	0.0123	0.0168	0.0247	0.0292
82	0.03831	0.01916	0.0122	0.0166	0.0244	0.0288
83	0.03785	0.01893	0.0120	0.0165	0.0241	0.0285
84	0.03740	0.01870	0.0119	0.0163	0.0238	0.0282
85	0.03696	0.01848	0.0118	0.0161	0.0235	0.0279
86	0.03653	0.01827	0.0116	0.0160	0.0233	0.0276
87	0.03611	0.01806	0.0115	0.0158	0.0230	0.0273
88	0.03570	0.01785	0.0114	0.0156	0.0227	0.0270
89	0.03530	0.01765	0.0112	0.0155	0.0225	0.0267
90	0.03491	0.01745	0.0111	0.0153	0.0222	0.0264
91	0.03452	0.01726	0.0110	0.0152	0.0220	0.0262
92	0.03415	0.01707	0.0109	0.0150	0.0217	0.0259
93	0.03378	0.01689	0.0108	0.0149	0.0215	0.0257
94	0.03342	0.01671	0.0106	0.0148	0.0213	0.0254
95	0.03307	0.01653	0.0105	0.0146	0.0211	0.0252
96	0.03273	0.01636	0.0104	0.0145	0.0208	0.0249
97	0.03239	0.01619	0.0103	0.0144	0.0206	0.0247
98	0.03206	0.01603	0.0102	0.0142	0.0204	0.0244
99	0.03173	0.01587	0.0101	0.0141	0.0202	0.0242
100	0.03142	0.01571	0.0100	0.0140	0.0200	0.0240
101	0.03110	0.01555	0.0099	0.0139	0.0198	0.0238
102	0.03080	0.01540	0.0098	0.0138	0.0196	0.0236
103	0.03050	0.01525	0.0097	0.0137	0.0194	0.0234
104	0.03021	0.01510	0.0096	0.0135	0.0192	0.0232
105	0.02992	0.01496	0.0095	0.0134	0.0190	0.0230
106	0.02964	0.01482	0.0094	0.0133	0.0189	0.0228
107	0.02936	0.01468	0.0093	0.0132	0.0187	0.0226
108	0.02909	0.01454	0.0093	0.0131	0.0185	0.0224
109	0.02882	0.01441	0.0092	0.0130	0.0183	0.0222
110	0.02856	0.01428	0.0091	0.0129	0.0182	0.0220
111	0.02830	0.01415	0.0090	0.0128	0.0180	0.0218
112	0.02805	0.01403	0.0089	0.0127	0.0179	0.0216
113	0.02780	0.01390	0.0088	0.0126	0.0177	0.0215
114	0.02756	0.01378	0.0088	0.0125	0.0175	0.0213
115	0.02732	0.01366	0.0087	0.0124	0.0174	0.0211
116	0.02708	0.01354	0.0086	0.0123	0.0172	0.0210
117	0.02685	0.01343	0.0085	0.0123	0.0171	0.0208
118	0.02662	0.01331	0.0085	0.0122	0.0169	0.0206
119	0.02640	0.01320	0.0084	0.0121	0.0168	0.0205

TABLE 16*c*.—GEAR TOOTH PARTS.—*Continued*
Fine Pitch Series
(A. G. M. A. recommended practice)

Diametral Pitch	Circular Pitch	Circular Thickness	Addendum	Dedendum	Working Depth	Whole Depth
120	0.02618	0.01309	0.0083	0.0120	0.0167	0.0203
121	0.02596	0.01298	0.0083	0.0119	0.0165	0.0202
122	0.02575	0.01288	0.0082	0.0118	0.0164	0.0200
123	0.02554	0.01277	0.0081	0.0118	0.0163	0.0199
124	0.02534	0.01267	0.0081	0.0117	0.0161	0.0197
125	0.02513	0.01257	0.0080	0.0116	0.0160	0.0196
126	0.02493	0.01247	0.0079	0.0115	0.0159	0.0195
127	0.02474	0.01237	0.0079	0.0114	0.0157	0.0193
128	0.02454	0.01227	0.0078	0.0114	0.0156	0.0192
129	0.02435	0.01218	0.0078	0.0113	0.0155	0.0191
130	0.02417	0.01208	0.0077	0.0112	0.0154	0.0189
131	0.02398	0.01199	0.0076	0.0112	0.0153	0.0188
132	0.02380	0.01190	0.0076	0.0111	0.0152	0.0187
133	0.02362	0.01181	0.0075	0.0110	0.0150	0.0185
134	0.02344	0.01172	0.0075	0.0110	0.0149	0.0184
135	0.02327	0.01164	0.0074	0.0109	0.0148	0.0183
136	0.02310	0.01155	0.0074	0.0108	0.0147	0.0182
137	0.02293	0.01147	0.0073	0.0108	0.0146	0.0181
138	0.02277	0.01138	0.0073	0.0107	0.0145	0.0179
139	0.02260	0.01130	0.0072	0.0106	0.0144	0.0178
140	0.02244	0.01122	0.0071	0.0106	0.0143	0.0177
141	0.02228	0.01114	0.0071	0.0105	0.0142	0.0176
142	0.02212	0.01106	0.0070	0.0105	0.0141	0.0175
143	0.02197	0.01098	0.0070	0.0104	0.0140	0.0174
144	0.02182	0.01091	0.0069	0.0103	0.0139	0.0173
145	0.02167	0.01083	0.0069	0.0103	0.0138	0.0172
146	0.02152	0.01076	0.0068	0.0102	0.0137	0.0171
147	0.02137	0.01069	0.0068	0.0102	0.0136	0.0170
148	0.02123	0.01061	0.0068	0.0101	0.0135	0.0169
149	0.02108	0.01054	0.0067	0.0101	0.0134	0.0168
150	0.02094	0.01047	0.0067	0.0100	0.0133	0.0167
151	0.02081	0.01040	0.0066	0.0099	0.0132	0.0166
152	0.02067	0.01033	0.0066	0.0099	0.0132	0.0165
153	0.02053	0.01027	0.0065	0.0098	0.0131	0.0164
154	0.02040	0.01020	0.0065	0.0098	0.0130	0.0163
155	0.02027	0.01013	0.0064	0.0097	0.0129	0.0162
156	0.02014	0.01007	0.0064	0.0097	0.0128	0.0161
157	0.02001	0.01001	0.0064	0.0096	0.0127	0.0160
158	0.01988	0.00994	0.0063	0.0096	0.0127	0.0159
159	0.01976	0.00988	0.0063	0.0095	0.0126	0.0158
160	0.01964	0.00982	0.0063	0.0095	0.0126	0.0158
161	0.01951	0.00976	0.0062	0.0095	0.0124	0.0157
162	0.01939	0.00970	0.0062	0.0094	0.0123	0.0156
163	0.01927	0.00964	0.0061	0.0094	0.0123	0.0155
164	0.01916	0.00958	0.0061	0.0093	0.0122	0.0154

HELICAL GEARS

The term "spiral gears" was formerly applied to all gears in which the teeth were not parallel with the axis. They were also called "skew gears." Later the term spiral gears was applied to helical gears made to replace bevel gears and used on shafts that were not parallel in both planes. This designation was used in previous editions of this Handbook. The teeth of such gears are, however, helices instead of spirals, and the correct term has been adopted in the present edition. The only approach to a spiral gear in practice is the "spiral bevel," and the term is retained for that form of gear only.

TABLE 17.—CALCULATION OF 45-DEGREE HELICAL GEARS

Pitch of Cutter	Pitch Diam.	Pitch of Helical in Inches to One Turn	No. of Teeth in Spur Same Curvature	Outside Diam.	Thickness of Tooth at Pitch Line (Normal)	Depth of Tooth	Clearance	Circular Pitch (Normal)
	Multiply by Number of Teeth in Helical Gear			Add to P.D.				
2	0.70710	2.22142	2.828	1.0000	0.7854	1.0785	0.0785	1.5708
2¼	0.62855	1.97464	2.828	0.8888	0.6981	0.9587	0.0699	1.3963
2½	0.56566	1.77707	2.828	0.8000	0.6283	0.8628	0.0628	1.2566
2¾	0.51425	1.61556	2.828	0.7273	0.5712	0.7844	0.0572	1.1424
3	0.47140	1.48094	2.828	0.6666	0.5236	0.7190	0.0524	1.0472
3½	0.40406	1.26939	2.828	0.5714	0.4488	0.6163	0.0449	0.8976
4	0.35355	1.11071	2.828	0.5000	0.3927	0.5393	0.0393	0.7854
5	0.28283	0.88853	2.828	0.4000	0.3142	0.4314	0.0314	0.6283
6	0.23570	0.74047	2.828	0.3333	0.0618	0.3595	0.0262	0.5236
7	0.20203	0.63469	2.828	0.2857	0.2244	0.3081	0.0224	0.4488
8	0.17677	0.55534	2.828	0.2500	0.1965	0.2696	0.0196	0.3927
9	0.15714	0.49367	2.828	0.2222	0.1745	0.2397	0.0175	0.3491
10	0.14143	0.44431	2.828	0.2000	0.1571	0.2157	0.0157	0.3142
11	0.12856	0.40388	2.828	0.1818	0.1428	0.1961	0.0143	0.2856
12	0.11785	0.37024	2.828	0.1666	0.1309	0.1798	0.0131	0.2618
14	0.10101	0.31733	2.828	0.1429	0.1122	0.1541	0.0112	0.2244
16	0.08836	0.27759	2.828	0.1250	0.0982	0.1348	0.0098	0.1963
18	0.07855	0.24677	2.828	0.1111	0.0873	0.1198	0.0088	0.1745
20	0.07071	0.22214	2.828	0.1000	0.0785	0.1079	0.0079	0.1571
22	0.06428	0.20194	2.828	0.0909	0.0714	0.0980	0.0071	0.1428
24	0.05892	0.18510	2.828	0.0833	0.0654	0.0898	0.0065	0.1309
26	0.05437	0.17081	2.828	0.0769	0.0604	0.0829	0.0060	0.1208
28	0.05050	0.15865	2.828	0.0714	0.0561	0.0770	0.0056	0.1122
30	0.04713	0.14806	2.828	0.0666	0.0524	0.0719	0.0053	0.1047
32	0.04425	0.13901	2.828	0.0625	0.0491	0.0674	0.0050	0.0982
36	0.03929	0.12343	2.828	0.0555	0.0436	0.0599	0.0043	0.0785
40	0.03533	0.11099	2.828	0.0500	0.0393	0.0539	0.0039	0.0873
48	0.02944	0.09249	2.828	0.0417	0.0327	0.0449	0.0033	0.0654

In considering speed ratios for helical gears the driving gear can be taken as a worm having as many threads as there are teeth and the driven as the worm gear with its number of teeth, so that one revolution of the driver will turn a point on the pitch circle of the driven gear as many inches as the lead of the teeth of the driver. Divide this by the circumference of the pitch circle of the driven gear to get the revolutions of the driven.

While the subject of helical gears is rather complex if considered broadly, most of the difficulties disappear when they have a tooth angle of 45 degrees. It is perhaps for this reason from from 75 to 90 per cent of the helical gears used are made with this angle.

This has the added advantage of being the most durable, although there is but a trifling increase in wear down to 30 degrees, and the wear at 20 degrees is not serious. In cases of necessity, even 12 degrees can be used without destructive wear.

Where higher speed ratios than can be had with a 45-degree angle tooth are necessary, they can be laid out as will be shown later and can be cut on most milling machines. The usual change gears allow about two thousand different helices to be cut.

Where the angles are not 45 degrees, the gear with the greatest angle must always be the driver.

All the tooth parts are derived from the normal pitch, whereas the pitch diameters are derived from the circular pitch. These are never the same in two gears of a pair except when both are 45 degrees.

As the diameter of a helical gear does not indicate its speed ratio, the terms *driver* and *follower* are used in place of gear and pinion.

45-Degree Helical Gear

These gears are the simplest of all helices to lay out and to make, the required speed ratios being obtained by varying the diameters, precisely as with spur or bevel gears, the rules for the speed ratio being the same in both cases. Moreover, the various factors required in laying out and making such gears can be reduced to the simple table shown on page 276. This was calculated by the late E. J. Kearney. With it any one can quickly make the few calculations connected with any pair of 45-degree gears having teeth between 2 and 48 diametral pitch.

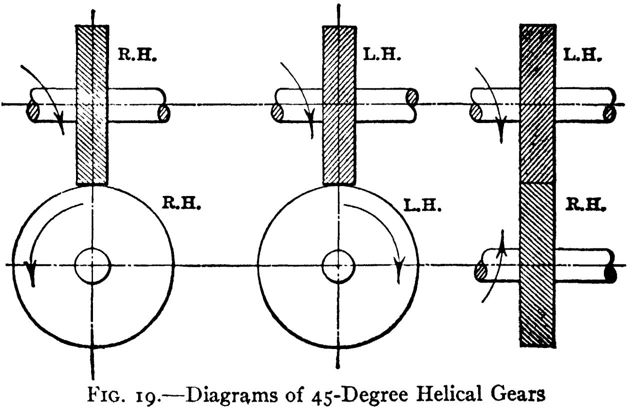

FIG. 19.—Diagrams of 45-Degree Helical Gears

EXAMPLE.—Let it be desired to construct a pair of helical gears with 35 teeth in the gear and 16 teeth in the pinion, using a 10-pitch cutter. Using the table on page 276, we have for a 10-pitch cutter, under the proper columns, the following:

P.D. = 0.14143 × 35 = 4.950.

O.D. = 4.950 + 0.200 = 5.150.

Pitch in inches to one turn of spiral = 0.44431 × 35 = 15.550.

NOTE.—A slight variation in one turn makes no practical difference; hence, the ordinary change gears furnished with a universal miller will usually be found sufficient.

Number of teeth in spur with same curvature = 2.828 × 35 = 98.980.

Looking at Brown and Sharpe spur-gear-cutter list, we see that 99 is between 55 and 134; therefore, we select a No. 2 cutter.

In a similar manner, using 16 as a multiplier, we obtain the data for the pinion. This gives 2.262 as pitch diameter, so that the center distance $= \frac{4.950 + 2.262}{2} = 3.606$.

The various dimensions follow:

	Gear	Pinion
Number of teeth	35	16
Pitch diameter	4.950	2.262
Outside diameter	5.150	2.462
Pitch in inches to one turn	15.550	7.108
Angle of helix	45°	45°
Pitch of cutter	10	10
Number of cutter	2	3
Whole depth of tooth	0.216	0.216
Angle of shafts	90°	
Center distance of shafts	3.606	

Figuring Helical Gears

As there is no direct solution for a pair of helical gears, their calculation is a tedious process and the result must be found by trial.

As numerous calculations are absolutely necessary, this formula should not involve division by large or fractional numbers and should contain the fewest possible operations. Such formulas are:

Let C = center distance.
P = diametral pitch.
N_1 = number of teeth in the driver.
N_2 = number of teeth in the follower.
S_1 = helix angle of driver.
S_2 = helix angle of follower.

Then $$2C = \frac{(\sec S_1 N_1) + (\sec S_2 N_2)}{P}.$$

That is, the sum of the secant of the driving angle times the number of teeth in the driver, and the secant of the follower angle times the

number of teeth in it, divided by the diametral pitch equals twice the center distance. This formula is derived as follows: The secant of the helix angle times the pitch diameter of a spur gear of the same number of teeth and pitch equals the pitch diameter of a helical gear of that angle, the pitch of the spur gear being the same as the normal pitch of the helical gear. Now for a spur gear, the number of teeth divided by the diametral pitch equals the pitch diameter. Therefore, *the secant of the helix angle* $\times \frac{N}{P} =$ *the pitch diameter of a helical gear.* The combined pitch diameters times the center distance are equal to

$$\left(\sec S_1 \times \frac{N_1}{P}\right) + \left(\sec S_2 \times \frac{N_2}{P}\right)$$

or $(\sec S_1 N_1) + (\sec S_2 N_2)$ for one diametral pitch.

The quantity $\sec S_1 N_1$ is the pitch diameter for the driver, and $\sec S_2 N_2$ is the pitch diameter of the follower. To obtain the center distance for any other pitch, it is simply necessary to divide this last result by that pitch.

A table of secants will furnish constants covering the entire range of angles; and therefore, all possible solutions for a pair of gears. After long experience in calculating helical gears these are recommended by C. H. Logue as the best and simplest for all cases.

Points to Be Kept in Mind When Calculating Helical Gears

To assist in their use the following points should be kept in mind:

1. The diameter of a helical gear increases with its angle.
2. Therefore, the diameter of the follower will reduce as the driving angle is increased, although not necessarily in the same ratio.
3. It is quite possible for the center distance to remain practically constant through quite a range of angles, the follower decreasing as the driver is increased. This is especially true when the gear having the greater number of teeth is the driver.
4. If the center distance is too great when the driving angle is 45 degrees—it must not go below that in any case—a lower number of teeth must be selected for both driver and follower, while maintaining the same ratio, and another trial made using a much higher angle for the driver.
5. The center distance will increase with the angle of the driver. This increase is more rapid when reducing than when increasing the speed of the follower. This refers to parallel shafts.
6. The number of teeth selected for each trial must be in proportion to the desired ratio.
7. Forty-five degrees is commonly accepted as the most efficient driving angle.

Selecting Secants and Trial Numbers of Teeth

To calculate a pair of helical gears, select secants for the desired angles, assuming the normal pitch, try out the value of $2C$ with trial numbers of teeth for driver and follower.

If the value $2C$ is too small, increase the number of teeth and try again. A very few calculations will show the number of teeth to secure the closest result.

If the center distance thus found is not as desired the angles must be shifted, keeping in mind the general laws governing the change of the center distance with the angle.

It is often found that when the desired center distance is reached the driving angle is too large to be desirable. The only alternative is to change the normal pitch and try again. A slide rule will give approximate results.

When there are limitations placed on the diameter of one or both of the gears, the following formula is of value. It may also serve as a check on the above calculations. The pitch diameters are assumed.

$$\tan S_1 = \frac{(\text{P.D. of driver} \times \text{number of revolutions of driver})}{(\text{P.D. of follower} \times \text{number of revolutions of follower})}.$$

This will set a limit on the driving angle S_1, to exceed which means that the gear will be too large.

Real Pitches for Circular-Pitch Helical Gears

The following Table 18, will be found convenient in figuring particulars for helical gearing, because it eliminates much of the work by shortening the process, thus making it quite an easy and simple matter to find the dimensions for either helical gears with axes parallel to each other or for gears with right-angle drive.

Formulas for use with the table are as follows: Circumference on pitch line = real pitch multiplied by number of teeth.

Lead of helix = circumference on pitch line divided by the tangent.

Pitch diameter = circumference divided by 3.1416.

For whole diameter add the same amount above pitch line as for spur wheels of the same pitch as the normal pitch.

The following is an example of the use of the table: A pair of wheels is required to be: ratio, 6 to 1; normal pitch, 1 inch; driver, 6 teeth; follower, 36 teeth; angle for driver, 66 degrees; angle for follower, 24 degrees.

Referring to the table, we find that the real pitch for the driver is 2.4585.

2.4585 × 6 (teeth) = 14.751 (circumference on pitch line).

Cir. 14.751 ÷ 2.246 (tangent) = 6.567 (lead of helix).

Cir. 14.751 ÷ 3.1416 = 4.695 (pitch diameter).

For the follower the real pitch is 1.0946.

1.0946 × 36 = 39.4056 (circumference).

Cir. 39.4056 ÷ 0.4452 (tangent) = 88.512 (lead of spiral).

Cir. 39.4056 ÷ 3.1416 = 12.543 (pitch diameter).

Another method of finding the lead of helix is to multiply the real pitch by the number of teeth, but for this purpose take the real pitch of the mating wheel.

In the above example we should have

Real pitch of follower, 1.0946 × 6 = 6.5676 (lead of helix).

Real pitch of driver, 2.4585 × 36 = 88.506.

It will be noticed that there is a slight difference in the result, but this is unimportant, as it is only brought about by the dropping of a few decimal points in the tangent.

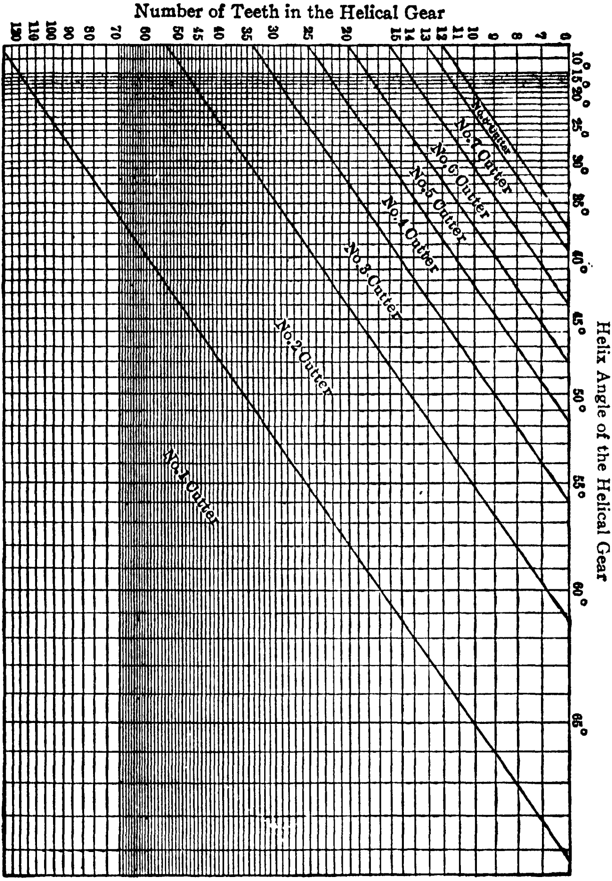

FIG. 20.—Chart for Selecting Helical Gear Cutters

Spur-Gear Cutters for Helical Gears

To find the number of a spur-gear cutter to be used in cutting a given helical gear, locate the intersection of lines traced from the points representing the number of teeth and the helix angle on the two scales. The number in the area on the chart within which the intersection falls is the cutter number of Brown and Sharpe's involute cutter system required.

MEASURING HELICAL GEARS WITH WIRES

The measurement of helical gears presents several difficulties that are not present in measuring spur gears. The calculations are more difficult because of the fact that the teeth curve in a helix instead of being straight. Also the different methods of producing helical gears such as milling, shaping, and hobbing may produce teeth which differ slightly from a true involute form.

In some plants steel balls are used to measure helical gears. They are theoretically preferable to measuring wires in that they do not rock when placed in the helical groove between the gear teeth. Steel balls, however, are available only in a few standard sizes in sixteenths or thirty-seconds of an inch, while measuring wires can be obtained in any special size which may be required to simplify calculations.

In making a measurement over two measuring wires placed in a helical gear, the gear should be placed on a surface plate and the micrometer spindle and anvil should be aligned with the face of the gear with two equal gage blocks or parallels, as shown in Fig. 20*a*. Then if the gear is moved until a maximum reading is obtained the correct measurement will be obtained.

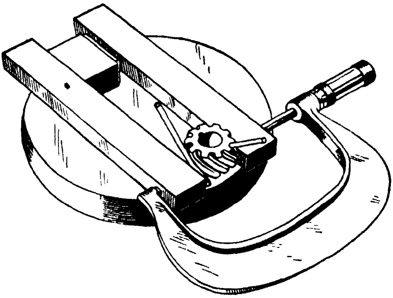

FIG. 20*a*.—Holding and Aligning Measuring Wires on a Helical Gear.

USING SPUR GEAR TABLES FOR HELICAL GEARS

The following method of measuring helical gears, using a special size of measuring wires $\frac{1.728}{\text{Normal DP}}$ and the spur gear tables previously given, is presented as one which appears to be approximately correct. It should, if possible, be supplemented by measurements over master gears.

NOTES ON HELICAL GEARS

GIVEN	MATHEMATICAL DATA
Helical Gear 12 teeth = N	cosine 45 degrees $= 0.70711$
6 DP 2-inch pitch diameter	$\dfrac{1}{\text{cosine 45 degrees}} = 1.4142$
45-degree helix angle 14½-degree pressure angle	$\dfrac{1}{(\text{cosine 45 degrees})^3} = 2.828$

1. Find normal DP $= \dfrac{6}{\text{cosine 45-degrees}} = 6 \times 1.4142 = 8.4852$

2. Find wire diameter $= \dfrac{1.728 \text{ inch}}{\text{Normal DP}} = \dfrac{1.728 \text{ inch}}{8.4852} = 0.20377$ inch

3. Find number of teeth in equivalent spur gear. $N' = \dfrac{1}{\text{cosine 45 degrees}} = 12 \times 1.4142 = 16.9704$

4. Find number of teeth for which cutter would be selected. $n = \dfrac{12}{(\text{cosine 45 degrees})^3} = 12 \times 2.828 = 33.94$

5. Find measurement for 1 DP. $= M$

Use decimal only from table for n teeth (33.94)

Use nearest whole number 34 . . . . = 0.4526 inch

Add $N' + 2$ . . . . = 18.9704 inches

M . . . . = 19.4230 inches

6. M for given helical gear $= \dfrac{M}{\text{Normal DP}} = \dfrac{19.4230}{8.4852} = 2.2890$ inches

The above procedure is used for gears having an even number of teeth. For gears of an odd number proceed as outlined above but correct the measurements for the wires not being opposite by ½ tooth interval as follows:

$$M \text{ for odd number of teeth} = (M - \text{wire diameter}) \times \cos \frac{90^\circ}{N} + \text{wire diameter}$$

The table for even tooth gears should be used for both even tooth gears and odd tooth gears. The decimal may be interpolated for the nearest whole number of N. For an instance the decimal for 37 teeth would be the average for 36 and 38 teeth or $\dfrac{0.4567 + 0.4604}{2}$ = 0.4585 inch.

TABLE 17a.—TABLE FOR EVEN TOOTH HELICAL GEARS

Helix Angle s	$\frac{1}{\cos s}$	$\frac{1}{(\cos s)^3}$	Helix Angle s	$\frac{1}{\cos s}$	$\frac{1}{(\cos s)^3}$
5°	1.0038	1.011	37°	1.2521	1.963
10	1.0154	1.047	38	1.2690	2.044
12	1.0223	1.068	39	1.2867	2.130
14	1.0306	1.095	40	1.3054	2.225
16	1.0403	1.126	41	1.3250	2.326
17	1.0457	1.143	42	1.3456	2.437
18	1.0515	1.163	43	1.3673	2.556
19	1.0576	1.183	44	1.3902	2.687
20	1.0642	1.205	45	1.4142	2.828
21	1.0711	1.229	46	1.4395	2.983
22	1.0785	1.254	47	1.4663	3.152
23	1.0864	1.280	48	1.4945	3.338
24	1.0946	1.309	49	1.5242	3.541
25	1.1034	1.343	50	1.5557	3.765
26	1.1126	1.377	51	1.5890	4.012
27	1.1223	1.414	52	1.6243	4.285
28	1.1326	1.453	53	1.6616	4.588
29	1.1433	1.495	54	1.7013	4.924
30	1.1547	1.540	55	1.7434	5.297
31	1.1666	1.588	56	1.7883	5.719
32	1.1792	1.640	57	1.8361	6.190
33	1.1924	1.695	58	1.8871	6.720
34	1.2062	1.755	59	1.9416	7.319
35	1.2208	1.819	60	2.0000	8.000
36	1.2361	1.889			

TABLE 17*b*.—ODD TOOTH HELICAL GEARS

Values of $\frac{\cos 90^\circ}{N}$ for use only in measuring odd-tooth gears*

N	$\cos \frac{90 \text{ degree}}{N}$	*N*	$\cos \frac{90 \text{ degree}}{N}$	*N*	$\cos \frac{90 \text{ degree}}{N}$
5	0.95106	41	0.99927	71	0.99976
7	0.97493	43	0.99933	73	0.99977
9	0.98481	45	0.99939	75	0.99978
		47	0.99944	77	0.99979
11	0.98982	49	0.99949	79	0.99980
13	0.99271				
15	0.99452				
17	0.99573				
19	0.99658	51	0.99953	81	0.99981
		53	0.99956	83	0.99982
21	0.99720	55	0.99959	85	0.99983
23	0.99767	57	0.99962	87	0.99984
25	0.99803	59	0.99965	89	0.99984
27	0.99831				
29	0.99853				
31	0.99872	61	0.99967	91	0.99985
33	0.99887	63	0.99969	93	0.99986
35	0.99899	65	0.99971	95	0.99986
37	0.99910	67	0.99973	97	0.99987
39	0.99919	69	0.99974	99	0.99987

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* When *N* is over 100 use formula given for even-tooth gears.

TABLE 18.—REAL PITCHES FOR CIRCULAR-PITCH HELICAL GEARS

Angles from Axis		Normal Pitches													
		1/4"		5/16"		3/8"		7/16"		1/2"		5/8"		3/4"	
Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower
80°	10°	1.4396	0.2538	1.7996	0.3173	2.1595	0.3808	2.5194	0.4442	2.8793	0.5077	3.5992	0.6346	4.3190	0.7616
79°	11°	1.3102	0.2546	1.6377	0.3183	1.9653	0.3820	2.2928	0.4457	2.6304	0.5093	3.2755	0.6366	3.9306	0.7640
78°	12°	1.2024	0.2556	1.5030	0.3195	1.8036	0.3833	2.1042	0.4473	2.4049	0.5112	3.0060	0.6390	3.6072	0.7666
77°	13°	1.1113	0.2565	1.3892	0.3207	1.6669	0.3848	1.9449	0.4490	2.2226	0.5131	2.7784	0.6414	3.3338	0.7696
76°	14°	1.0334	0.2576	1.2917	0.3220	1.5500	0.3865	1.8084	0.4509	2.0668	0.5153	2.5834	0.6440	3.1000	0.7730
75°	15°	0.9659	0.2591	1.2074	0.3238	1.4489	0.3885	1.6903	0.4529	1.9318	0.5181	2.4148	0.6476	2.8978	0.7772
74°	16°	0.9069	0.2600	1.1337	0.3250	1.3605	0.3901	1.5872	0.4551	1.8139	0.5201	2.2674	0.6502	2.7210	0.7802
73°	17°	0.8550	0.2614	1.0688	0.3268	1.2826	0.3931	1.4964	0.4575	1.7101	0.5228	2.1377	0.6536	2.5652	0.7842
72°	18°	0.8090	0.2628	1.0112	0.3286	1.2135	0.3943	1.4157	0.4600	1.6180	0.5257	2.0225	0.6572	2.4270	0.7886
71°	19°	0.7678	0.2644	0.9598	0.3305	1.1518	0.3966	1.3438	0.4627	1.5357	0.5288	1.9196	0.6610	2.3036	0.7932
70°	20°	0.7309	0.2660	0.9137	0.3325	1.0964	0.3990	1.2791	0.4656	1.4619	0.5320	1.8274	0.6651	2.1928	0.7981
69°	21°	0.6976	0.2678	0.8720	0.3347	1.0464	0.4017	1.2208	0.4686	1.3952	0.5356	1.7440	0.6694	2.0928	0.8034
68°	22°	0.6673	0.2696	0.8342	0.3370	1.0010	0.4044	1.1679	0.4718	1.3346	0.5392	1.6684	0.6740	2.0020	0.8088
67°	23°	0.6398	0.2716	0.7998	0.3395	0.9597	0.4074	1.1120	0.4752	1.2796	0.5432	1.5996	0.6790	1.9194	0.8148
66°	24°	0.6146	0.2736	0.7683	0.3420	0.9220	0.4105	1.0756	0.4789	1.2292	0.5472	1.5366	0.6841	1.8440	0.8210
65°	25°	0.5915	0.2758	0.7394	0.3448	0.8873	0.4137	1.0352	0.4827	1.1830	0.5516	1.4788	0.6896	1.7746	0.8274
64°	26°	0.5702	0.2781	0.7129	0.3477	0.8554	0.4172	0.9980	0.4868	1.1406	0.5563	1.4258	0.6954	1.7108	0.8344
63°	27°	0.5507	0.2806	0.6883	0.3507	0.8260	0.4209	0.9636	0.4910	1.1014	0.5612	1.3766	0.7014	1.6520	0.8418
62°	28°	0.5325	0.2831	0.6656	0.3539	0.7988	0.4247	0.9319	0.4955	1.0650	0.5662	1.3312	0.7078	1.5976	0.8494
61°	29°	0.5157	0.2858	0.6446	0.3573	0.7735	0.4287	0.9024	0.5002	1.0314	0.5716	1.2892	0.7146	1.5470	0.8574
60°	30°	0.5000	0.2886	0.6250	0.3608	0.7500	0.4330	0.8750	0.5051	1.0000	0.5773	1.2500	0.7216	1.5000	0.8660
59°	31°	0.4853	0.2916	0.6067	0.3646	0.7281	0.4375	0.8494	0.5104	0.9708	0.5833	1.2134	0.7292	1.4562	0.8750
58°	32°	0.4717	0.2948	0.5897	0.3685	0.7076	0.4422	0.8256	0.5159	0.9435	0.5896	1.1794	0.7370	1.4152	0.8844
57°	33°	0.4590	0.2981	0.5738	0.3726	0.6885	0.4471	0.8033	0.5216	0.9180	0.5962	1.1476	0.7452	1.3770	0.8942
56°	34°	0.4470	0.3015	0.5588	0.3769	0.6706	0.4523	0.7824	0.5277	0.8941	0.6031	1.1176	0.7538	1.3412	0.9046
55°	35°	0.4358	0.3052	0.5448	0.3815	0.6538	0.4578	0.7627	0.5341	0.8717	0.6104	1.0896	0.7630	1.3076	0.9156
54°	36°	0.4253	0.3090	0.5316	0.3862	0.6380	0.4635	0.7443	0.5408	0.8506	0.6180	1.0632	0.7724	1.2760	0.9270
53°	37°	0.4154	0.3130	0.5192	0.3913	0.6231	0.4695	0.7269	0.5478	0.8308	0.6260	1.0384	0.7826	1.2462	0.9390
52°	38°	0.4060	0.3172	0.5076	0.3965	0.6091	0.4759	0.7161	0.5552	0.8121	0.6345	1.0152	0.7930	1.2182	0.9518
51°	39°	0.3972	0.3217	0.4965	0.4021	0.5959	0.4825	0.6952	0.5628	0.7945	0.6434	0.9930	0.8042	1.1918	0.9650
50°	40°	0.3889	0.3264	0.4861	0.4079	0.5834	0.4895	0.6806	0.5711	0.7778	0.6527	0.9722	0.8159	1.1668	0.9790
49°	41°	0.3810	0.3312	0.4763	0.4140	0.5716	0.4969	0.6668	0.5797	0.7621	0.6625	0.9526	0.8280	1.1432	0.9938
48°	42°	0.3736	0.3364	0.4670	0.4205	0.5604	0.5046	0.6538	0.5887	0.7472	0.6728	0.9340	0.8410	1.1208	1.0092
47°	43°	0.3665	0.3418	0.4582	0.4272	0.5498	0.5127	0.6415	0.5982	0.7331	0.6836	0.9164	0.8544	1.0996	1.0254
46°	44°	0.3598	0.3475	0.4498	0.4344	0.5398	0.5213	0.6298	0.6082	0.7197	0.6950	0.8996	0.8688	1.0796	1.0426
45°	45°	0.3536	0.3536	0.4419	0.4419	0.5303	0.5303	0.6187	0.6187	0.7071	0.7071	0.8839	0.8839	1.0606	1.0606

Angles from Axis		Normal Pitches												Tangent of Angle	
		7/8"		1"		1 1/8"		1 1/4"		1 3/8"		1 1/2"			
Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower
80°	10°	5.0388	0.8884	5.7587	1.0154	6.4785	1.1423	7.1983	1.2692	7.8192	1.3962	8.6380	1.5230	5.6713	0.1763
79°	11°	4.5856	0.8914	5.2407	1.0187	5.8961	1.1460	6.5510	1.2732	7.2061	1.4007	7.8612	1.5280	5.1446	0.1944
78°	12°	4.2084	0.8946	4.8098	1.0223	5.4109	1.1501	6.0122	1.2780	6.6134	1.4057	7.2146	1.5335	4.7046	0.2126
77°	13°	3.8898	0.8980	4.4454	1.0263	5.0001	1.1546	5.5568	1.2828	6.1125	1.4111	6.6681	1.5394	4.3315	0.2309
76°	14°	3.6168	0.9018	4.1336	1.0306	4.6500	1.1594	5.1669	1.2882	5.6837	1.4171	6.2004	1.5459	4.0108	0.2493
75°	15°	3.3806	0.9058	3.8637	1.0353	4.3466	1.1658	4.8296	1.2952	5.3126	1.4248	5.7955	1.5543	3.7321	0.2679
74°	16°	3.1744	0.9102	3.6279	1.0403	4.0814	1.1703	4.5348	1.3004	4.9884	1.4304	5.4419	1.5604	3.4874	0.2867
73°	17°	2.9928	0.9150	3.4203	1.0457	3.8478	1.1764	4.2754	1.3071	4.7029	1.4378	5.1304	1.5685	3.2709	0.3057
72°	18°	2.8314	0.9200	3.2360	1.0515	3.6405	1.1829	4.0450	1.3143	4.4495	1.4457	4.8540	1.5771	3.0777	0.3249
71°	19°	2.6876	0.9254	3.0715	1.0576	3.4554	1.1898	3.8394	1.3220	4.2233	1.4542	4.6072	1.5864	2.9042	0.3443
70°	20°	2.5582	0.9312	2.9238	1.0641	3.2892	1.1972	3.6548	1.3302	4.0202	1.4632	4.3857	1.5962	2.7475	0.3640
69°	21°	2.4416	0.9372	2.7904	1.0711	3.1391	1.2050	3.4880	1.3389	3.8368	1.4728	4.1856	1.6067	2.6051	0.3839
68°	22°	2.3358	0.9436	2.6694	1.0785	3.0030	1.2133	3.3369	1.3480	3.6705	1.4829	4.0041	1.6178	2.4751	0.4040
67°	23°	2.2240	0.9504	2.5593	1.0863	2.8792	1.2221	3.1991	1.3580	3.5190	1.4937	3.8389	1.6295	2.3559	0.4245
66°	24°	2.1512	0.9578	2.4585	1.0946	2.7659	1.2314	3.0732	1.3682	3.3805	1.5051	3.6876	1.6418	2.2460	0.4452
65°	25°	2.0704	0.9654	2.3662	1.1033	2.6619	1.2412	2.9577	1.3792	3.2535	1.5171	3.5493	1.6550	2.1445	0.4663
64°	26°	1.9960	0.9736	2.2811	1.1127	2.5663	1.2517	2.8515	1.3908	3.1366	1.5298	3.4218	1.6689	2.0503	0.4877
63°	27°	1.9272	0.9820	2.2026	1.1223	2.4780	1.2626	2.7533	1.4029	3.0287	1.5431	3.3040	1.6835	1.9626	0.5095
62°	28°	1.8638	0.9910	2.1300	1.1326	2.3963	1.2741	2.6625	1.4157	2.9288	1.5572	3.1950	1.6988	1.8807	0.5317
61°	29°	1.8048	1.0004	2.0626	1.1433	2.3205	1.2862	2.5783	1.4292	2.8361	1.5721	3.0940	1.7150	1.8040	0.5543
60°	30°	1.7500	1.0102	2.0000	1.1548	2.2500	1.2990	2.5000	1.4433	2.7500	1.5877	3.0000	1.7320	1.7321	0.5774
59°	31°	1.6988	1.0208	1.9415	1.1667	2.1843	1.3125	2.4269	1.4583	2.6696	1.6042	2.9134	1.7499	1.6643	0.6009
58°	32°	1.6512	1.0318	1.8870	1.1790	2.1229	1.3266	2.3588	1.4740	2.5947	1.6213	2.8306	1.7687	1.6003	0.6249
57°	33°	1.6066	1.0432	1.8360	1.1923	2.0655	1.3414	2.2951	1.4904	2.5246	1.6395	2.7451	1.7885	1.5399	0.6494
56°	34°	1.5648	1.0554	1.7883	1.2062	2.0118	1.3569	2.2353	1.5077	2.4589	1.6585	2.6824	1.8093	1.4826	0.6745
55°	35°	1.5254	1.0682	1.7434	1.2207	1.9614	1.3734	2.1793	1.5260	2.3972	1.6786	2.6151	1.8311	1.4281	0.7002
54°	36°	1.4886	1.0816	1.7012	1.2360	1.9139	1.3905	2.1266	1.5449	2.3392	1.6997	2.5519	1.8541	1.3764	0.7265
53°	37°	1.4538	1.0956	1.6614	1.2521	1.8693	1.4086	2.0070	1.5652	2.2847	1.7217	2.4924	1.8781	1.3270	0.7536
52°	38°	1.4322	1.1104	1.6242	1.2690	1.8273	1.4276	2.0303	1.5862	2.2333	1.7449	2.4364	1.9035	1.2799	0.7813
51°	39°	1.3904	1.1256	1.5890	1.2867	1.7876	1.4476	1.9862	1.6084	2.1847	1.7693	2.3835	1.9301	1.2349	0.8098
50°	40°	1.3612	1.1422	1.5557	1.3054	1.7502	1.4686	1.9446	1.6317	2.1391	1.7949	2.3336	1.9581	1.1918	0.8391
49°	41°	1.3336	1.1594	1.5240	1.3250	1.7148	1.4906	1.9054	1.6562	2.0958	1.8219	2.2863	1.9875	1.1504	0.8693
48°	42°	1.3076	1.1774	1.4944	1.3456	1.6813	1.5138	1.8681	1.6820	2.0549	1.8502	2.2417	2.0184	1.1106	0.9004
47°	43°	1.2830	1.1964	1.4662	1.3673	1.6495	1.5382	1.8328	1.7089	2.0161	1.8001	2.1994	2.0510	1.0724	0.9325
46°	44°	1.2596	1.2164	1.4395	1.3901	1.6194	1.5639	1.7994	1.7377	1.9792	1.9114	2.1593	2.0852	1.0355	0.9657
45°	45°	1.2374	1.2374	1.4142	1.4142	1.5910	1.5910	1.7678	1.7678	1.9445	1.9445	2.1213	2.1213	1.0000	1.0000

To Find Helix Angle of Old Gear

Find normal circular pitch by measuring whole depth of tooth and thickness at pitch line. Subtract twice the addendum to get the pitch diameter. Multiply pitch diameter by 3.1416, and divide by the number of teeth to get the real circular pitch. Divide the normal circular pitch by the real circular pitch which gives cosine of helix angle on which gear is cut.

To get the lead, multiply the circumference by the cotangent of helix angle, or divide by the tangent.

Helical-Gear Table

While it is better in every case to understand the principles involved before using tables as this tends to prevent errors, they can be used with good results by simply following directions carefully. The subject of helical gears is so much more complicated than other gears that many will prefer to depend entirely on the tables.

Table 19 gives the circular pitch and addendum or the diametral pitch and lead of helices for one diametral pitch and with teeth having angles of from 1 to 89 degrees to 45 and 45 degrees. For other pitches, divide the addendum given and the helix number by the required pitch, and multiply the results by the required number of teeth. This will give the pitch diameter and lead of helix for each wheel. For the outside diameter add two diametral pitches as in spur gearing.

Suppose we want a pair of helical gears with 10- and 80-degree angles, 8-diametral-pitch cutter, with 16 teeth in the small gear, having a 10-degree angle and 10 teeth in the large gear with its 80-degree angle.

Find the 10-degree angle of helix and in the third column find 1.0154. Divide by pitch, 8, and get 0.1269. Multiply this by number of teeth — $0.1269 \times 16 = 2.030 =$ pitch diameter. Add 2 pitches — two $\frac{1}{8} = \frac{1}{4}$ and $2.030 + 0.25 = 2.28$ inches outside diameter.

The lead of helix for 10 degrees for small wheel is 18.092. Divide by pitch $= 18.092 \div 8 = 2.2615$. Multiply by number of teeth, $2.2615 \times 16 = 36.18$, the lead of helix, which means that it makes one turn in 36.18 inches.

For the other gear with its 80-degree angle, find the addendum, 5.7587. Divide by pitch, 8, obtaining 0.7198. Multiply by number of teeth, 10, obtaining 7.198. Add two pitches, or 0.25, obtaining 7.448 as outside diameter.

The lead of helix is 3.1901. Divide by pitch, 8, obtaining 0.3988. Multiply by number of teeth to obtain 3.988 the lead of helix.

When racks are to mesh with helical gears, divide the number in the circular pitch columns for the given angle by the required diametral pitch to get the corresponding circular pitch.

If we want to make a rack to mesh with a 40-degree helical gear of 8 pitch: Look for circular pitch opposite 40 and find 4.101. Divide by 8, obtaining 0.512 as the circular pitch for this angle. The greater the angle, the greater the circular or linear pitch, as can

TABLE 19.—HELICAL-GEAR TABLE

Shaft Angles 90 Degrees for One Diametral Pitch

Angle of Helix Degrees	To obtain the circular pitch for one tooth, divide by the required diametral pitch	To obtain the pitch diameter, divide by the required diametral pitch and multiply the quotient by the required number of teeth	To obtain the lead of helix, divide by the required diametral pitch and multiply quotient by the required number of teeth		To obtain the pitch diameter, divide by the required diametral pitch and multiply the quotient by the required number of teeth	To obtain the circular pitch for one tooth, divide by the required diametral pitch.	Angle of Helix in Degrees
	Circular Pitch	One Tooth or Addend.	Lead of Helix		One Tooth or Addendum	Circular Pitch	
Small Wheel	Small Wheel	Small Wheel	Small Wheel	Large Wheel	Large Wheel	Large Wheel	Large Wheel
1	3.1419	1.0001	180.05	3.1420	57.298	180.01	89
2	3.1435	1.0006	90.020	3.1435	28.653	90.016	88
3	3.1457	1.0013	60.032	3.1458	19.107	60.026	87
4	3.1491	1.0024	45.038	3.1492	14.335	45.035	86
5	3.1535	1.0038	37.077	3.1527	11.473	36.044	85
6	3.1589	1.0055	30.056	3.1589	9.5667	30.055	84
7	3.1652	1.0075	25.728	3.1651	8.2055	25.778	83
8	3.1724	1.0098	22.573	3.1724	7.1852	22.573	82
9	3.1806	1.0124	20.082	3.1807	6.3924	20.082	81
10	3.1900	1.0154	18.092	3.1901	5.7587	18.092	80
11	3.2003	1.0187	16.464	3.2003	5.2408	16.464	79
12	3.2145	1.0232	15.076	3.2105	4.8097	15.104	78
13	3.2242	1.0263	13.966	3.2294	4.4454	13.988	77
14	3.2377	1.0306	12.986	3.2378	4.1335	12.986	76
15	3.2522	1.0352	12.138	3.2524	3.8637	12.138	75
16	3.2679	1.0402	11.393	3.2678	3.6279	11.397	74
17	3.2848	1.0456	10.417	3.2821	3.4203	10.745	73
18	3.3116	1.0514	10.192	3.3032	3.2360	10.166	72
19	3.3225	1.0576	9.6494	3.3225	3.0715	9.6494	71
20	3.3430	1.0641	9.1848	3.3433	2.9238	9.1854	70
21	3.3650	1.0711	8.7662	3.3652	2.7904	8.7663	69
22	3.3882	1.0785	8.3862	3.3833	2.6694	8.3862	68
23	3.4127	1.0863	8.0399	3.4129	2.5593	8.0403	67
24	3.4451	1.0946	7.7379	3.4391	2.4585	7.7242	66
25	3.4661	1.1033	7.4332	3.4663	2.3662	7.4336	65
26	3.4953	1.1126	7.1664	3.4952	2.2811	7.1663	64
27	3.5258	1.1223	6.9198	3.5257	2.2026	6.9197	63
28	3.5579	1.1325	6.6912	3.5575	2.1300	6.6916	62
29	3.5918	1.1433	6.4799	3.5919	2.0626	6.4799	61
30	3.6276	1.1547	6.2778	3.6277	2.0000	6.2832	60
31	3.6650	1.1666	6.0979	3.6652	1.9416	6.0997	59
32	3.7043	1.1791	5.9282	3.7044	1.8870	5.9282	58
33	3.7457	1.1923	5.7710	3.7459	1.8360	5.7680	57
34	3.7894	1.2062	5.6181	3.7826	1.7882	5.6178	56
35	3.8349	1.2207	5.4754	3.8351	1.7434	5.4770	55
36	3.8830	1.2360	5.3431	3.8834	1.7013	5.3448	54
37	3.9336	1.2521	5.2201	3.9261	1.6616	5.2200	53
38	3.9867	1.2690	5.1028	3.9921	1.6242	5.1026	52
39	4.0482	1.2867	4.9866	4.0416	1.5890	4.9920	51
40	4.1010	1.3054	4.8873	4.1012	1.5557	4.8874	50
41	4.1626	1.3250	4.7885	4.1540	1.5242	4.7884	49
42	4.2273	1.3456	4.6949	4.2272	1.4944	4.6948	48
43	4.2956	1.3673	4.6065	4.2956	1.4662	4.6062	47
44	4.3671	1.3901	4.5223	4.3675	1.4395	4.5225	46
45	4.4428	1.4142	4.4428	4.4428	1.4142	4.4428	45

be seen by trying an 80-degree angle. Here the circular pitch is 2.261 inches.

Testing and Adjusting Spiral Bevel-Gear Drives[1]

The proper adjustment of bevel gears in assembly is a vital factor in obtaining quiet and durable gears.

There are two distinct considerations in obtaining the proper tooth contact: one is the bearing along the tooth, the lengthwise bearing; the other, the bearing up and down the tooth, or profile bearing, and it is essential that the two be considered separately to obtain the proper results in combination. Diagram shows terms used.

Graphic definitions of the terms used in describing the proper procedure to mount a pair of bevel gears are given herewith.

Bevel gears are cut with a predetermined amount of backlash to suit the pitch and operating conditions, and this backlash should not be altered by any great amount to obtain the proper tooth contact, as the necessity of such a step indicates a fault either in the cutting or in the alignment of the supporting bearings. The usual amount of blacklash is from 0.004 inch on 8-pitch gears to 0.012 inch on 3-pitch gears.

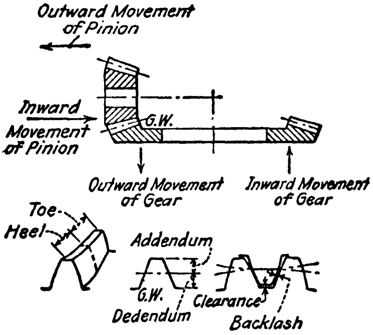

FIG. 21

Bevel gears mounted in a rigid testing machine should show a bearing toward the small end of the tooth, and the amount the bearing favors the small end is determined experimentally by the stiffness of the mounting in which the gears are to be finally assembled. Any spring in the mounting of the gears under load will cause the bearing to move toward the large end, and in no case should the bearing be heaviest at the large end of the tooth under the operating load. Any extra load, such as induced by suddenly applying the full load, will cause the bearing to become concentrated on the top corner of the large end of the tooth and breakage will ensue. The figures below show typical tooth bearings as obtained in a testing machine and when mounted in an automobile axle, also the effect of spring in the mounting on the apexes of the gear and pinion. It will be observed that the apexes do not coincide when the gear mounting has sprung under the working load. Therefore, when cutting the gears, it is necessary to make provision for this lift or spring.

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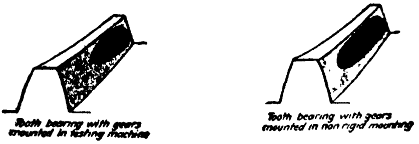
[1] By permission of the Gleason Works, Rochester, N. Y.

Bevel gears are commonly cut to run flush at the large end of the teeth and, as a first step, they should be so assembled in the mounting for an initial trial. Powdered red lead and any light machine oil should be mixed and spread over the working surfaces of the teeth with a brush to show clearly the tooth contact obtained.

There is no difference in the method of adjusting spiral or straight bevels, and, while the following statements are particularly applicable for spiral bevels, they are also true for straight bevels.

After mounting the gears flush with the proper amount of backlash, they should be operated under load in each direction for a minute. In the automobile rear-axle driving gears, the rear axle should first be raised to have the wheels clear the floor, then the motor started and the wheels driven in both directions with the brakes applied to obtain the necessary load.


Tooth bearing with gears mounted in testing machine

Tooth bearing with gears mounted in non rigid mounting

FIG. 22.—Effect of Mounting

All figures show the bearing on the gear tooth. With a right-hand spiral bevel gear (mating with a left-hand spiral pinion) mounted in an automobile, the driving side is on the convex side of the tooth, and the concave side of the tooth is used when in reverse.

The tooth bearing, both lengthwise and profile, should appear as shown in *A* and *B*, Fig. 23, but a condition of tooth contact may be obtained, as indicated in *C* to *N*. The lengthwise bearing adjustments will first be considered.

Figures *C* and *D* show what is called a cross bearing, which is caused by either a misalignment of the mounting or an error in the cutting. The mounting should be tested and, if found faulty, should be corrected. If the drive side has a toe bearing and the reverse a heel bearing, the gears are serviceable, provided the bearing is about five-eighths of the tooth length, but if the heel bearing occurs on the drive side, it should not be used, and the cutting conditions should be altered if the mounting is found correct.

Figures *E* and *F* show a toe bearing on each side of the tooth and the gear must be moved away from the pinion to increase the lengthwise bearing, which, on ratios 1:1 to approximately 4:1, will change the profile bearing to some extent and an adjustment of the pinion may be required. This movement of the gear will introduce more backlash, and the gear cutting should be changed in order to properly locate the bearing if this increase in backlash becomes excessive.

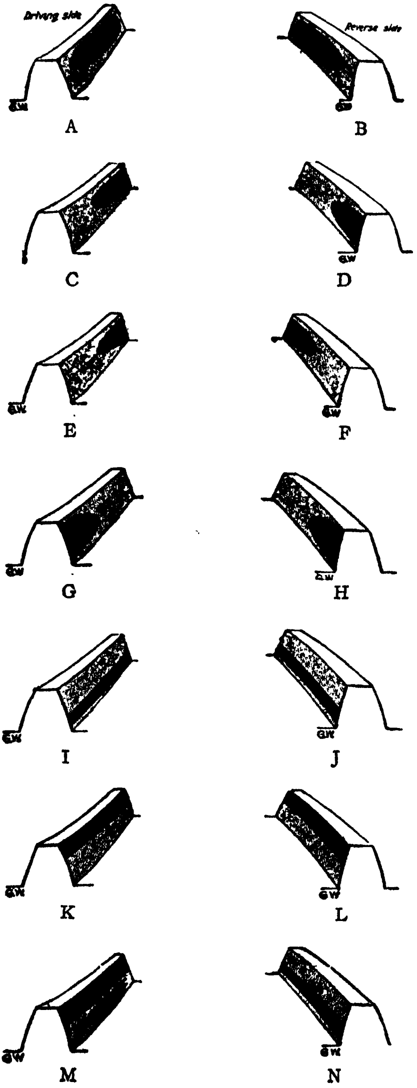


FIG. 23.—Spiral Bevel Tooth Bearing

Figures *G* and *H* show a heel bearing on both sides, and the gear must be adjusted toward the pinion to increase the lengthwise bearing, which, on ratios 1:1 to approximately 4:1, will change the profile bearing to some extent and an adjustment of the pinion may be required.

Figures *I* and *J* show a low bearing on gear tooth which may appear at any position along the tooth. The pinion should be moved away from the gear, and on ratios 1:1 to approximately 4:1, the gear should be moved toward the pinion to maintain the proper backlash. This movement of the gear will alter the lengthwise bearing, and several adjustments for both lengthwise and profile bearing may be required to obtain the proper tooth bearing.

Figures *K* and *L* show a high bearing on gear tooth which may appear at any position along the tooth. The pinion should be moved toward the gear, and on ratios 1:1 to approximately 4:1, the gear should be moved away from the pinion to maintain the backlash. This movement of the gear will alter the lengthwise bearing and several adjustments for both lengthwise and profile bearing may be required.

Figures *M* and *N* show a lame bearing. It is possible to adjust the gears and obtain a fair driving condition, as shown at *A*, Fig. 23, but a poor coast or reverse. The only method of completely eliminating the trouble is to cut the gears properly.

It must be borne in mind that the adjustment cited should be moderate, and if great amounts of adjustments are needed, the mounting and gear cutting must be carefully checked and the necessary steps taken to correct trouble in the making of the gears or mounting. The convex side of tooth should drive.

TOLERANCES IN GEARING

The tolerances (Table 20) were proposed by Harry Horsington, ordnance engineer at Rock Island Arsenal, in 1925. It is suggested that a very flexible feeler be used as a "not-go" gage in testing backlash in spur gears.

It should be remembered that manufacturing tolerances of gages must be considered which will reduce the actual component or work tolerance. It will be observed that, in the tables shown, the clearances between the shafts have not been considered. Allowance has been made in the tables for close work and in order that the necessary oil film in the bearing will absorb part of the essential bearing clearance and the remainder will take care of the tolerances in the gages. It should also be remembered that these tables are for production work and that closer fits may be secured by special fitting or selective assembly.

Speeds and Feeds for Gear Cutting
Brown & Sharpe Mfg. Co.

	Feet per Minute
Carbon-steel cutters on cast iron	40–60
Carbon-steel cutters on steel	30–40
High-speed steel cutters—cast iron	80–125
High-speed steel cutters—steel	65–100

TABLE 20.—PROPOSED TOLERANCES FOR SPUR GEARS AND SUPPORTS

Twenty-degree involute, closest practical work on production basis, presupposing high speed, hardened and ground gears or accurately cut gears.

Diameter Pitch	Running Clearance Expressed as Backlash	Allowable Variation in Each Gear	Maximum Amount Each Tooth Space is Widened, Including Half Clearance	Necessary Allowed Variation in Center Distance	Backlash Resulting from Maximum Center Distance	Greatest Allowable Backlash in Pair, Assembled	Allowable Variation from Theoretical Center Distance of One Gear and Correct Master Rack
2	0.004	+0.0025	+0.0045	+0.003	0.0022	0.012	−0.0027——0.0061
2.5	0.004	0.0025	0.0045	0.00275	0.0020	0.011	0.0027– 0.0061
3	0.003	0.0025	0.004	0.00275	0.0020	0.010	0.0021– 0.0055
3.5	0.0025	0.00235	0.0036	0.0025	0.0018	0.009	0.0017– 0.005
4	0.002	0.0022	0.0032	0.0025	0.0018	0.008	0.0014– 0.0044
5	0.002	0.0016	0.0026	0.0025	0.0018	0.007	0.0014– 0.0036
6	0.0015	0.0015	0.00225	0.0025	0.0018	0.0065	0.001 – 0.0031
7	0.0015	0.0015	0.00225	0.002	0.0015	0.006	0.001 – 0.0031
8	0.001	0.0015	0.002	0.002	0.0015	0.0055	0.0007– 0.0027
9	0.001	0.0015	0.002	0.0015	0.0011	0.005	0.0007– 0.0027
10	0.0008	0.0015	0.0019	0.001	0.0007	0.0045	0.0005– 0.0026
12	0.0008	0.001	0.0014	0.001	0.0007	0.004	0.0005– 0.002
14–18	0.0006	0.001	0.0013	0.001	0.0007	0.0033	0.0015
20	0.0004	0.001	0.0012	0.001	0.0006	0.003	0.0015

TABLE 21.—PROPOSED TOLERANCES FOR SPUR GEARS AND SUPPORTS

Twenty-degree involute, ordinary conditions with cut gears—not hardened. Good center distance fixtures. Assembling without fitting or selection. Suitable for gun-carriage elevating and traversing-gear trains.

Diameter Pitch	Running Clearance Expressed as Backlash. In Pair	Allowable Variation in Width of Space. Either Gear	Maximum Amount Each Tooth Space is Widened, Including Clearance in Column 2	Necessary Allowed Variation in Center Distance of Shaft	Backlash Resulting from Maximum Center Distance	Greatest Resulting Backlash in Pair, Assembled	Allowable Variation from Theoretical Center Distance of One Gear and Correct Master Rack
2	0.010	0.0028	+0.0078	+0.007	0.0051	0.021	−0.0069−−0.0107
2.5	0.0075	0.0025	0.0063	0.0065	0.0047	0.017	0.0052− 0.0087
3	0.0054	0.0025	0.0052	0.006	0.0044	0.015	0.0037− 0.0071
3.5	0.004	0.0025	0.0045	0.005	0.0036	0.014	0.0027− 0.0062
4	0.0028	0.0025	0.0039	0.0034	0.0029	0.011	0.0019− 0.0054
5	0.0026	0.0025	0.0038	0.003	0.0022	0.010	0.0018− 0.0052
6	0.002	0.0021	0.0031	0.0025	0.0018	0.008	0.0014− 0.0043
7	0.0017	0.0019	0.0027	0.0025	0.0018	0.0072	0.0012− 0.0037
8	0.0012	0.0018	0.0024	0.002	0.0015	0.0063	0.0008− 0.0033
9	0.0008	0.0017	0.0021	0.002	0.0015	0.0057	0.0005− 0.0029
10	0.0008	0.0015	0.0019	0.0015	0.0011	0.0049	0.0005− 0.0026
12	0.0008	0.0012	0.0016	0.001	0.0007	0.0039	0.0005− 0.0022

The most economical feed is not the fastest which the cutter will stand without burning or breaking. This is due to the fact that with a very high rate of feed the cutter must be ground frequently, and this consumes considerable time. There is also the risk of a ruined cutter. A slightly slower feed in such a case will not greatly decrease the rate of production, but it will, on the other hand, allow the cutter to hold its edge much longer. The result will be that the net production per cutter will be greater at the slower feed, and the production per day will be as great. This reduces the cutter cost, inasmuch as the cutters last much longer under the slightly slower feed.

Diameter Pitch		2	2½	3	4	5	6	7	8	10	12	16
Feed in inches per minute	Cast iron.......	4	4	4½	5	6	6	7	7	8	9	11
	Steel...........	2½	2½	3	3	3½	3½	4½	4½	5	6	8

Grinding Gear Teeth.—Gear teeth have been ground for many years, but the practice was not common until some automobile builders adopted it for transmission gears. There are several types of machines: one using a wheel shaped to the space between the gear teeth, grinding both sides at once; another using the perpendicular side of a thin wheel, the gear being rolled past the wheel and the outside of the wheel being set to or near the bottom of the tooth space; another, using a wheel shaped like a theoretical rack tooth, grinding both sides at once; and still another, grinding with a narrow edge at the side of the wheel. Two of these machines use bands, a third uses a master gear and rack, and the fourth operates much as the conventional rotary-type gear cutter. These machines correct the distortion due to hardening and can produce a true tooth form.

Shaving, Burnishing, and Lapping Gears.—Machines have been developed for shaving gear teeth after cutting to improve both contour and surface before hardening. Shaving tools are either hardened racks or hard gears with fine serrations on the teeth. Fellows, Michigan, and National machines are used.

Gears are also burnished by being run under pressure with hardened master gears. In some cases, gear teeth are lapped after hardening by running mating gears together with a fine abrasive compound, but this is not common practice. They are also lapped by reciprocating inside an internal gear of same size and pitch.

Spline Hobbing.—Spline hobbing experience seems to apply in gear hobbing as well. R. B. Haynes finds that

1. Climb hobbing always yields a finish on the sides of the splines obviously superior to that obtainable by conventional cutting. This superiority is observed so easily that customers, during the early stages of the application, brought much pressure to bear to hasten the completion of the project.
2. Climb hobbing is accompanied invariably by an increase in hob life. This increase normally amounts to from 20 to 30 per cent more pieces per hob.

TABLE 22.—PROPOSED TOLERANCES FOR CLOSE-FITTING WORM GEARING Applicable to General Ordnance Construction

Threads per Inch	Maximum Separation of Center Distance from Theoretical	Backlash				Maximum Angular Movement in Degrees of Worm Shaft (Assembled Work)	In Fixtures with Correct Theoretical Center Distances	
		Resulting from Increased Center Distances (20-degree Involute)	Worm	Worm Wheel	Total		Worm and Master Wheel	Wheel and Master Worm
1	0–+0.003	0.00218	+0.001–+0.005	0.004	0.01118	4.02	1.8	1.44
1.5	0.003	0.00218	0.0045	0.0035	0.01018	5.50	2.43	1.89
2	0.003	0.00218	0.004	0.003	0.00918	6.61	2.88	2.16
2.5	0.00275	0.002	0.004	0.00275	0.00875	7.88	3.6	2.48
2.667	0.00275	0.002	0.004	0.00275	0.00875	8.40	3.84	2.64
3	0.00275	0.002	0.00375	0.0025	0.00825	8.91	4.05	2.66
3.5	0.0025	0.00182	0.00375	0.0025	0.00807	10.17	4.72	3.15
4	0.0025	0.00182	0.0035	0.0025	0.00782	11.26	5.18	3.60
5	0.0025	0.00182	+0.0005–+0.00325	0.002	0.00707	12.73	6.35	3.60
6	0.0025	0.00182	0.003	0.00175	0.00657	14.19	6.48	3.78
7	0.002	0.00146	0.0025	0.00175	0.00571	14.39	6.30	4.41
8	0.002	0.00146	0.00225	0.0015	0.00521	15	6.12	4.32
9	0.0015	0.00109	0.00225	0.0015	0.00484	15.68	7.29	4.86
10	0.001	0.00073	0.00225	0.0015	0.00448	16.13	8.1	5.4

3. Climb hobbing consumes less power per cubic inch of metal removed. This decrease normally will be in the ratio of 1.00 horse-power for climb hobbing to 1.10 horse-power for conventional hobbing.
4. Climb hobbing produces little or no burr on the splines, thereby reducing, or in some cases eliminating, subsequent burring operations.
5. The value of climb hobbing as a production process is not affected materially by coolants, speeds, feeds, or other factors in the operation.

Nonmetallic Gear (Composition Gears).—Many gears are now made of rawhide or a cotton fabric impregnated with compositions of the Bakelite order and are made under several well-known trade names. They reduce noise when meshed with metal gears and are sufficiently elastic to cushion shocks that might break cast-iron gears. They are quite effectively impervious to oil or water but should not be run in water.

The composition can be machined much like metal, but much faster. In sawing, a band saw with $5\frac{1}{2}$ teeth per inch and 0.04 inch thick is suggested. Drills will cut a trifle small and heat and are frequently ground off-center to prevent this. Reamers tend to leave holes from 0.001 to 0.002 below size.

Cutting off or trepanning tools should have plenty of side clearance. An 8-degree clearance behind the cutting edge and 5- to 10-degree top rake are recommended.

A cutting emulsion is sometimes used in drilling and reaming.

The teeth of composition gears without metal backing can be cut at a very fast rate. It is best to have a support at the back of the gear to support the rim as the cutter or holes break through.

NONMETALLIC GEARS AND PINIONS[1]

Preferred Pitch

The pitch of the gear or pinion should bear a reasonable relation to the transmitted horse-power and speed, or to the applied torque.

Two preferred pitch tables are given, their choice being optional. Table 23 is based on the horse-power load at a given pitch-line velocity, while Table 24 is based on the applied torque.

The torque used in Table 24 is the pounds torque at a 1-foot radius, which for any given horse-power and speed can be obtained from the formula:

$$T = \frac{5{,}252\ \text{H.P.}}{\text{r.p.m.}}.$$

These preferred-pitch tables are applicable to both rawhide and phenolic laminated materials.

Bore Sizes

For plain phenolic laminated pinions, that is, without metal end plates, a drive fit of 0.001 inch per inch of shaft diameter should be used. Above 2.5 inches diameter shaft, the fit should be constant at 0.0025 to 0.003 inch.

Where metal reinforcing end plates are used, the drive fit should be of the same standard as used for metal.

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[1] Adopted as recommended practice by the American Gear Manufacturers Association.

TABLE 23

H.p. Rating	Up to 1,000 P.L.V.* D.P.	1,000 to 2,000 P.L.V. D.P.	Over 2,000 P.L.V. D.P.
½ to 1	8 to 10	10 to 12	12 to 16
1 to 2	7 to 8	8 to 10	10 to 12
2 to 3	6 to 7	7 to 8	8 to 10
3 to 7½	5 to 6	6 to 7	7 to 8
7½ to 10	4 to 5	5 to 6	6 to 7
10 to 15	3 to 4	4 to 5	5 to 6
15 to 25	2½ to 3	3 to 4	4 to 5
25 to 60	2 to 2½	2½ to 3	3 to 4
60 to 100	1¾ to 2	2 to 2½	2½ to 3
100 to 150	1½ to 1¾	1¾ to 2	2 to 2½

* Pitch-line velocity.

TABLE 24

D.P.	Torque in Foot-Pounds Minimum and Maximum
16	1– 2
12	2– 4
10	4– 8
8	8– 15
6	15– 30
5	30– 50
4	50– 100
3	100– 200
2½	200– 450
2	450– 900
1½	900–1,800
1	1,800–3,500

Relation of Bore to Pinion Diameter

The root diameter of the pinion of phenolic laminated type should be such that the minimum distance from the edge of the keyway to the root diameter shall be at least equal to the depth of tooth.

For rawhide pinions, this point is covered under the American Gear Manufacturers Association, "Adopted Standard for Rawhide Gears," revision of 1933.

Keyway Stresses

On a plain phenolic laminated gear or pinion, the keyway stress should not exceed 3,000 pounds per square inch.

The keyway stress is calculated by the formula

$$S = \frac{33{,}000 \times \text{H.P.}}{\text{P.L.S.} \times A}$$

If the keyway stress formula is expressed in terms of shaft radius and revolutions per minute, it will read:

$$S = \frac{63{,}000 \times \text{H.P.}}{\text{r.p.m.} \times r \times A}$$

where S = unit stress, in pounds per square inch.
H.P. = horse-power transmitted.
P.L.S. = peripheral speed of shaft in feet per minute.
A = area of keyway in pinion, in square inches. Length by height.
r = shaft radius.

When the design is such that the keyway stresses exceed 3,000 pounds per square inch, metal reinforcing end plates may be used. Such end plates should not extend beyond the root diameter of the teeth. The distance from the outer edge of the retaining bolt to the root diameter of the teeth shall not be less than a full tooth depth.

The use of drive keys should be avoided, but if required, metal end plates should be used on the pinion to take the wedging action of the key.

Mating Gear

The mating gear should be of cast iron or hard steel. Soft steel, brass, or soft bronze should be avoided. The teeth should be cut and in good condition for best results.

For phenolic laminated pinions, the face of the mating gear should be the same as, or slightly greater than, the pinion face.

A.G.M.A. FORMULA FOR COMPUTING THE HORSE-POWER OF NONMETALLIC SPUR GEARS COMPOSED OF LAMINATED PHENOLIC MATERIALS OR RAWHIDE

Adopted May, 1926—Revised May, 1927

$$\text{H.P.} = \frac{0.000095 \times \text{S.W.S.} \times \text{F.W.} \times Y \times \text{P.L.V.}}{\text{D.P.}}$$

where H.P. = horse-power.
S.W.S. = safe working stress of material (varies with speed; see value of S.W.S. in table following).
F.W. = face width in inches.
Y = constant depending upon number of teeth (see values of Y in table following).
P.L.V. = pitch-line velocity in feet per minute.
D.P. = diametral pitch.

VALUES OF S.W.S. FOR PITCH-LINE SPEED IN FEET PER MINUTE

P.L.V.	S.W.S.	P.L.V.	S.W.S.	P.L.V.	S.W.S.
100	4,500	700	2,500	1,700	1,974
150	4,071	800	2,400	1,800	1,950
200	3,750	900	2,318	1,900	1,929
250	3,500	1,000	2,250	2,000	1,909
300	3,300	1,100	2,192	2,200	1,875
350	3,136	1,200	2,143	2,300	1,860
400	3,000	1,300	2,100	2,400	1,846
450	2,885	1,400	2,063	2,600	1,821
500	2,786	1,500	2,029	2,800	1,800
600	2,625	1,600	2,000	3,000	1,781

6,000 pounds was used as the safe working stress for static load and with the formula

$$\left(\frac{150}{200 + \text{P.L.V.}} + 0.25\right) \times 6{,}000 = \text{S.W.S. in the table.}$$

VALUES OF *Y*
14½- and 20-degree Involute

Teeth	*Y*		Teeth	*Y*	
	14½°	20°		14½°	20°
12	0.067	0.078	27	0.100	0.111
13	0.070	0.083	30	0.102	0.114
14	0.072	0.088	34	0.104	0.118
15	0.075	0.092	38	0.107	0.122
16	0.077	0.094	43	0.110	0.126
17	0.080	0.096	50	0.112	0.130
18	0.083	0.098	60	0.114	0.134
19	0.087	0.100	75	0.116	0.138
20	0.090	0.102	100	0.118	0.142
21	0.092	0.104	150	0.120	0.146
23	0.094	0.106	300	0.122	0.150
25	0.097	0.108	rack	0.124	0.154

Values for *Y* same as used in Lewis formula.

The formula was derived from the Lewis formula for horse-power as follows:

$$\text{H.P.} = \frac{W \times \text{P.L.V.}}{33{,}000}.$$

$$W = \text{S.W.S.} \times \text{C.P.} \times \text{F.W.} \times Y.$$

Substituting

$$\text{H.P.} = \frac{\text{S.W.S.} \times \text{C.P.} \times \text{F.W.} \times Y \times \text{P.L.V.}}{33{,}000}.$$

Changing C.P. to D.P.

$$\text{H.P.} = \frac{\frac{\pi}{\text{D.P.}}\,(\text{S.W.S.} \times \text{F.W.} \times Y \times \text{P.L.V.}).}{33{,}000}.$$

Clearing fractions

$$\text{H.P.} = \frac{0.000095 \times \text{S.W.S.} \times \text{F.W.} \times Y \times \text{P.L.V.}}{\text{D.P.}}.$$

THREADS OF WORMS

Worms are often cut with threads having an included angle of 29 degrees similar to the Acme thread. This is true for single and double threads in particular, but for worms, for a greater number of threads, 40-degree included angle, and sometimes a 60-degree included angle, is used. It is also a common practice to use a straight-sided cutter of the respective included angle for the worms, and in this case the worm-thread sides will be curved and will not be like the cutter.

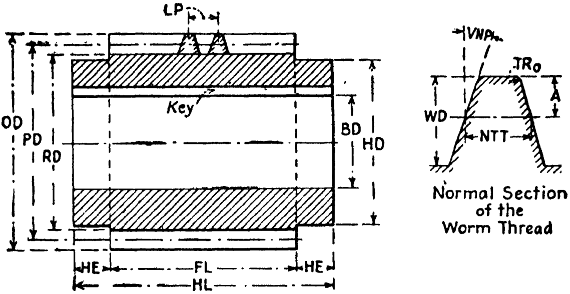


FIG. 24.—Threads of Worms

The design of worms is intimately involved with the worm gears with which it is to run and also with the hob with which the gear is cut, and while a few simple rules cannot cover them, the recommended practices of the American Gear Manufacturers Association will answer for most worms and gears.

The general industrial range is from ½ to 2 inches linear pitch, from single to quadruple and from 10:1 to 100:1 gear ratios. The standard-thread form is that produced by a straight-sided milling cutter of not less than the outside diameter of the worms or more than 1½ diameters. For single- and double-thread worms the side angle of cutter is 14½ degrees, and for triple- and quadruple-thread worms the side angle is 20 degrees. Single- and double-thread hobs

TABLE 25.—FORMULAS FOR WORMS

Terms	Symbols	Single and Double	Triple and Quadruple
Linear pitch	L.P.		
Pitch diameter	P.D.	2.4 × L.P. + 1.1	2.4 × L.P. + 1.1
Outside diameter	O.D.	3.036 × L.P. + 1.1	2.972 × L.P. + 1.1
Root diameter	R.D.	1.664 × L.P. + 1.1	1.726 × L.P. + 1.1.
Hub diameter	H.D.	1.663 × L.P. + 1	1.726 × L.P. + 1
Bore (maximum)	max. B.D.	L.P. + 0.625	L.P. + 0.625
Face length	F.L.	$\text{L.P.} \times \left(4.5 + \frac{\text{N.}}{50}\right)$	$\text{L.P.} \times \left(4.5 + \frac{\text{N.}}{50}\right)$
Hub extensions	H.E.	L.P.	L.P.
Hub length	H.L.	F.L. + 2 × L.P.	F.L. + 2 × L.P.
Keyway	Ky.	A.G.M.A. Std.	A.G.M.A. Std.
Addendum	A.	0.3183 × L.P.	0.2865 × L.P.
Whole depth of tooth	W.D.	0.686 × L.P.	0.623 × L.P.
Lead angle	V.L.	$\text{cot. V.L.} = \frac{\text{P.D.} \times 3.1416}{\text{Lead}}$	$\text{cot. V.L.} = \frac{\text{P.D.} \times 3.1416}{\text{Lead}}$
Normal tooth thickness	N.T.T.	0.5 × L.P. × cos. V.L.	0.5 × L.P. × cos. V.L.
Top round	T.Ro.	0.05 × L.P.	0.05 × L.P.
Lead	L.	No. of thds. × L.P.	No. of thds. × L.P.
Normal pressure angle	V.N.P.	$14\frac{1}{2}°$ degrees	20 degrees

To find the pitch and root diameters of any worm, see data on Worm Threads on page 51. For P.D. deduct 0.6366 × L.P. in inches from O.D. For R.D. deduct 2 × 0.6866 × L.P. in inches and add 0.005 in clearance on each side—or 0.01 in. total.

may be fluted parallel to axis. Triple- and quadruple-thread hobs should be fluted normal to the thread angle at outside diameter.

Standard linear pitches in inches are:

$\frac{1}{4}$, $\frac{5}{16}$, $\frac{3}{8}$, $\frac{1}{2}$, $\frac{5}{8}$, $\frac{3}{4}$, 1, $1\frac{1}{4}$, $1\frac{1}{2}$, $1\frac{3}{4}$, 2.

These, with multiple-thread worms, give 44 worms for various uses. Formulas for worms and worm wheels follow. Proportions are shown in Fig. 22.

EXAMPLE.—What are the dimensions of a 1 inch linear pitch double-thread worm which engages with a 50-tooth gear?

SYMBOL		FORMULA		DIMENSION
L.P.		Predetermined	as	1 in.
P.D.	=	$2.400 \times 1 + 1.1$	or	3.5 in.
O.D.	=	$3.036 \times 1 + 1.1$	or	4.136 in.
R.D.	=	$1.664 \times 1 + 1.1$	or	2.764 in.
H.D.	=	$1.664 \times 1 + 1$	or	2.664 in. = $2\frac{11}{16}$
max. B.D.	=	$1 + 0.625$	or	1.625
F.L.	=	$1 \times \left(4.5 + \frac{50}{50}\right)$	or	5.5 in.
H.E.	=	L.P.	or	1 in.
H.L.	=	$5.5 + 2 \times 1$	or	7.5 in.
Ky.	=	To A.G.M.A. Std.		
A.	=	0.318×1	or	0.318 in.
W.D.	=	0.686×1	or	0.686 in.
cot V.L.	=	$\frac{3.5 \times 3.1416}{2}$	or	0.49785 = 10 degrees 19 minutes
N.T.T.	=	$0.5 \times 1 \times 0.9838$	or	0.4919 in.
T.Ro.	=	0.05×1	or	0.05 in.
L.	=	1×2	or	2 in.
V.N.P.	=	Predetermined	as	14½ degrees

FORMULAS FOR STANDARD WORM GEARS

The proportions recommended for worm gears are based on the gears meshing with standard worms.

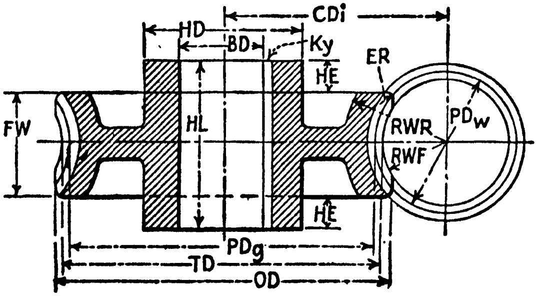


FIG. 25.—Proportions of Standard Worm Gears

TABLE 26.—FORMULAS FOR GEAR

Terms	Symbols	Single and Double	Triple and Quadruple
Circular pitch = (Worm Linear)	L.P.		
Number of teeth	N.		
Pitch diameter	P.D.	N. × 0.3183 × L.P.	N. × 0.3183 × L.P.
Throat diameter	T.D.	P.D. + (0.636 × L.P.)	P.D. + (0.572 × L.P.)
Outside diameter	O.D.	T.D. + (0.4775 × L.P.)	T.D. + (0.3183 × L.P.)
Hub diameter	H.D.	1.875 × Bo.	1.875 × Bo.
Keyway	Ky.	A.G.M.A. Std.	A.G.M.A. Std.
Face width	F.W.	2.38 × L.P. + 0.25	2.15 × L.P. + 0.2
Hub extensions	H.E.	0 25 × Bo.	0.25 × L.P.
Hub length	H.L.	F.W. + 0.5 × Bo.	F.W. + 0.5 × Bo.
Radius of wheel face	R.Fa.	0.882 × L.P. + 0.55	0.914 × L.P. + 0.55
Radius of wheel rim	R.Ri.	2.2 × L.P. + 0.55	2.1 × L.P. + 0.55
Edge round	E.Ro.	0.25 × L.P.	W.T. × L.P.
Center distance	Ct.D.	(P.Dg. + P.Dw.) × 0.5	(P.Dg. + P.Dw.) × 0.5
		(P.Dg. + P.Dw.) × 0.5	(P.Dg. + P.Dw.) × 0.5
Normal pressure angle	V.N.P.	14½ degrees	20 degrees

Example.—What are the dimensions of a 1 in. linear-pitch gear having 50 teeth and engaging with a double-thread worm? The bore is 2 inches.

Symbol	Formula	Dimension
L.P.	Predetermined	1 in.
N.	Predetermined	50
P.D.	= 0.3183 × 1 × 50	or 15.915 in.
T.D.	= 15.915 + (0.636 × 1)	or 16.551 in.
O.D.	= 16.551 + (0.4775 × 1)	or 17.028 in.
H.D.	= 1.875 × 2	or 3.750 in.
Ky.	= A.G.M.A. Std.	or $\frac{1}{2} \times \frac{1}{4}$ in.
F.W.	= 2.38 × 1 + .25	= 2.63 or $2\frac{5}{8}$ in.
H.E.	= 0.25 × 2	= 0.5 in.
H.L.	= 2.625 + 0.5 × 2	= 3.625 in.
R.Fa.	= 0.882 × 1 + 0.55	= 1.43 or $1\frac{7}{16}$
R.Ri.	= 2.2 × 1 + 0.55	= 2.75 or $2\frac{3}{4}$
E.Ro.	= 0.25 × 1	= 0.25 in.
Ct.D.	= 15.915 + 3.5 × 0.5	= 9.707 in.

Face of Wheel

For wheels engaging with single- or double-thread worms, the width of face should not be greater than the chord of the worm outside circle which is tangent to the worm pitch circle plus one-half of the linear pitch. For wheels engaging with triple and quadruple thread worms, the width of face should not be greater than the chord of the worm outside circle, which is tangent to the worm pitch circle plus one-quarter of the linear pitch.

Outside Diameters

For wheels meshing with single- or double-thread worms:

$$\text{O.D.} = \text{P.D.} + (3.5 \times A).$$

For wheels meshing with triple or quadruple thread worms, where the pressure angle is 20 degrees or greater:

$$\text{O.D.} = \text{P.D.} + (3 \times A).$$

For wheels meshing with triple or quadruple thread worms, where the pressure angle is less than 20 degrees:

$$\text{O.D.} = \text{P.D.} + (2.75 \times A).$$

Worm Pitch Diameter

The worms, of course, must be made to correspond to the pitch diameter of the hob in order to secure proper contact.

Length of Worm Face

The length of the worm may be made in accordance with the formula for standard worms:

$$\text{F.L.} = \text{L.P.} \times \left(4.5 + \frac{\text{N.}}{50}\right).$$

Hub Extensions

The hub extensions may be made in accordance with the formula:

$$\text{H.E.} = \text{L.P.}$$

TOP ROUND OF WORM THREAD

The radius which joins the outside and the sides of the rim of the wheel has been called the top round, and it is recommended that this be made equivalent to one-quarter the linear pitch.

Figures 26 and 27 show application of recommendations.

The top edge of the worm thread should in all cases be rounded to avoid cutting action in case the gears are not mounted on exact theoretical centers. The amount of the rounding may be made equivalent to 0.05 of the linear pitch.

A.G.M.A. Recommended Practice for the Design of Worm Gearing: Using Existing Hobs

For wheels meshing with single- or double-thread worms:

$$\text{F.W.} = 2 \times \sqrt{(\text{P.Dw.} + A) \times A} + (0.25 \times \text{L.P.})$$
$$\text{F.W.} = 2 \times \sqrt{(\text{P.Dw.} + A) \times A} + (0.5 \times \text{L.P.})$$
$$\text{O.D.} = \text{P.Dg.} + 3.5 \times \text{A}$$
$$\text{T.Ro.} = 0.25 \times \text{L.P.}$$

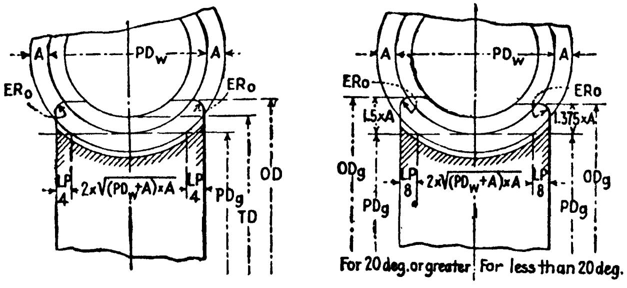


FIG. 26 FIG. 27

Designs of Worm Gearing

For wheels meshing with triple- or quadruple-thread worms:

$$\text{E.Ro.} = 0.25 \times \text{L.P.}$$

Where the pressure angle is 20 degrees or greater:

$$\text{O.D.} = \text{P.Cg} + 2.75 \times A.$$

Where the pressure angle is less than 20 degrees:

$$\text{O.D.} = \text{P.Dg.} + 3 \times A.$$

(See Lead Gears for Diametral Pitch Worms, Sec. I.

TABLE OF PROPORTIONS OF WORM THREADS TO RUN IN WORM WHEELS

TABLE 27.

C. P. Circular Pitch	pi. Threads per Inch	D. P. Dia-metrical Pitch	H. Tooth above Pitch-Line	D. Working Depth of Tooth	C. Clearance	S. Depth of Space below Pitch Line	W. D. Whole Depth of Tooth	T. Thickn. of Tooth on Pitch Line	W. Width of Thread Tool at End	B. Width of Thread at Top
C. P. Inches	$\text{pi.}=\frac{1}{\text{C. P.}}$	$\text{D.P.}=\frac{\pi}{\text{C. P.}}$	$\text{H.}=\frac{1}{\text{D. P.}}$	$\text{D.}=2\times\frac{1}{\text{D. P.}}$	$\text{C.}=\frac{\text{T}}{10}$	S.=H.+C.	W. D.= D.+C.	$\text{T.}=\frac{\text{C.P.}}{2}$	W.= .31×C.P.	B. = .335 ×C.P.
2	½	1.5708	.6366	1.2732	.1000	.7366	1.3732	1.0000	.6200	.6708
1¾	4/7	1.7952	.5570	1.1141	.0875	.6445	1.2016	.8750	.5425	.5862
1½	⅔	2.0944	.4775	.9549	.0750	.5525	1.0299	.7500	.4650	.5025
1¼	⅘	2.5133	.3979	.7958	.0625	.4604	.8583	.6250	.3875	.4187
1	1	3.1416	.3183	.6366	.0500	.3683	.6866	.5000	.3100	.3350
¾	1⅓	4.1888	.2387	.4775	.0375	.2762	.5150	.3750	.2325	.2512
⅔	1½	4.7124	.2122	.4244	.0333	.2455	.4577	.3333	.2066	.2233
½	2	6.2832	.1592	.3183	.0250	.1842	.3433	.2500	.1550	.1675
⅖	2½	7.8540	.1273	.2546	.0200	.1473	.2746	.2000	.1240	.1340
⅓	3	9.4248	.1061	.2122	.0166	.1227	.2288	.1666	.1033	.1117
2/7	3½	10.9956	.0909	.1819	.0143	.1052	.1962	.1429	.0886	.0957
¼	4	12.5664	.0796	.1591	.0125	.0921	.1716	.1250	.0775	.0838
2/9	4½	14.1372	.0707	.1415	.0111	.0818	.1526	.1111	.0689	.0744
⅕	5	15.7080	.0637	.1273	.0100	.0737	.1373	.1000	.0620	.0670
⅙	6	18.8496	.0531	.1061	.0083	.0614	.1144	.0833	.0517	.0558
1/7	7	21.9911	.0455	.0910	.0071	.0526	.0981	.0714	.0443	.0479
⅛	8	25.1327	.0398	.0796	.0062	.0460	.0858	.0625	.0388	.0419
1/9	9	28.2743	.0354	.0707	.0055	.0409	.0763	.0555	.0344	.0372
1/10	10	31.4159	.0318	.0637	.0050	.0368	.0687	.0500	.0310	.0335
1/12	12	37.6992	.0265	.0530	.0042	.0307	.0572	.0416	.0258	.0279
1/14	14	43.9824	.0227	.0454	.0036	.0263	.0490	.0357	.0221	.0239
1/16	16	50.2655	.0199	.0398	.0031	.0230	.0429	.0312	.0194	.0209
1/18	18	56.5488	.0176	.0352	.0025	.0201	.0377	.0255	.0172	.0186

Note.—The above table refers to single threads only. For Multiple threads, divide the sizes given in the table for the same **lead,** by 2 for double, 3 for triple, 4 for quadruple threads, etc.

To find the Pitch Diameter (given pitch and number of teeth).

Rule.—Multiply the number of teeth by the circular pitch and divide by 3.1416.

Example.—Number of teeth, 96; circular pitch, ¼. Then 96 × ¼ = 24. 24 ÷ 3.1416 = 7.639 = pitch diameter.—*Note.*—Diameter of Hob equals diameter of Worm plus twice the clearance "C."

TABLE 28.—GASHING ANGLES FOR WORM WHEELS

Lead of Worm in Inches	No. of Threads per Inch in Worm	Pitch Diameter of Worm															
		⅝	¾	⅞	1	1⅛	1¼	1⅜	1½	1⅝	1¾	1⅞	2	2⅛	2¼	2⅜	2½
1/10	10	2°55′	2°26′	2° 5′	1°49′	1°37′	1°28′	1°20′	1°13′	1° 7′	1° 2′	58′	55′	52′	49′	46′	44′
1/9	9	3°14′	2°42′	2°19′	2° 1′	1°48′	1°37′	1°28′	1°21′	1°15′	1° 9′	1° 5′	1° 1′	57′	54′	51′	49′
1/8	8	3°38′	3° 2′	2°36′	2°17′	2° 2′	1°49′	1°39′	1°31′	1°24′	1°18′	1°13′	1° 8′	1° 4′	1° 1′	58′	54′
1/7	7	4°10′	3°28′	2°58′	2°36′	2°19′	2° 5′	1°54′	1°44′	1°36′	1°29′	1°23′	1°18′	1°14′	1° 9′	1° 6′	1° 3′
1/6	6	4°51′	4° 3′	3°28′	3° 2′	2°42′	2°26′	2°13′	2° 1′	1°52′	1°44′	1°37′	1°31′	1°26′	1°21′	1°17′	1°13′
1/5	5	5°49′	4°51′	4°10′	3°39′	3°14′	2°55′	2°39′	2°26′	2°15′	2° 5′	1°57′	1°49′	1°43′	1°37′	1°32′	1°27′
1/4	4	7°16′	6° 4′	5°12′	4°33′	4° 3′	3°39′	3°19′	3° 2′	2°48′	2°36′	2°26′	2°17′	2° 9′	2° 2′	1°55′	1°49′
2/7	3½	8°17′	6°55′	5°56′	5°12′	4°37′	4°10′	3°47′	3°28′	3°12′	2°58′	2°47′	2°36′	2°27′	2°19′	2°12′	2° 5′
1/3	3	9°38′	8° 3′	6°55′	6° 3′	5°23′	4°51′	4°25′	4° 3′	3°44′	3°28′	3°14′	3° 2′	2°52′	2°42′	2°33′	2°26′
4/11	2¾	10°30′	8°46′	7°32′	6°36′	5°52′	5°17′	4°49′	4°25′	4° 4′	3°47′	3°32′	3°19′	3° 7′	2°57′	2°47′	2°39′
3/8	2⅔	10°49′	9° 3′	7°46′	6°48′	6° 4′	5°27′	4°58′	4°33′	4°12′	3°54′	3°39′	3°25′	3°13′	3° 2′	2°53′	2°44′
2/5	2½	11°31′	9°38′	8°17′	7°15′	6°27′	5°49′	5°17′	4°51′	4°29′	4°10′	3°53′	3°39′	3°26′	3°14′	3° 4′	2°55′
4/9	2¼				8° 3′	7°10′	6°27′	5°52′	5°23′	4°59′	4°37′	4°19′	4° 3′	3°46′	3°36′	3°25′	3°14′
1/2	2						7°15′	6°36′	6° 3′	5°36′	5°12′	4°51′	4°33′	4°17′	4° 3′	3°50′	3°39′
4/7	1¾								6°55′	6°23′	5°56′	5°32′	5°12′	4°54′	4°37′	4°23′	4°10′
2/3	1½											6°27′	6° 3′	5°42′	5°23′	5° 6′	4°51′
3/4	1⅓													6°25′	6° 3′	5°44′	5°27′
4/5	1¼															6° 7′	5°49′
1	1																
1⅓	¾																
1½	⅔																

TABLE 28.—GASHING ANGLES FOR WORM WHEELS.—*Continued*

Lead of Worm in Inches	No. of Threads per Inch in Worm	Pitch Diameter of Worm															
		2¼	2½	2¾	3	3¼	3½	3¾	4	4¼	4½	4¾	5	5¼	5½	5¾	6
1/10	10																
1/9	9																
1/8	8	52'	50'	48'	46'	42'	39'	36'	34'	32'							
1/7	7	1°	57'	54'	52'	48'	45'	42'	39'	37'	35'	33'					
1/6	6	1° 9'	1° 6'	1° 3'	1° 1'	56'	52'	48'	46'	43'	40'	38'	36'	35'			
1/5	5	1°23'	1°20'	1°16'	1°13'	1° 7'	1° 3'	58'	55'	52'	49'	46'	44'	42'	40'	38'	
1/4	4	1°44'	1°39'	1°35'	1°31'	1°24'	1°18'	1°13'	1° 8'	1° 4'	1° 1'	58'	55'	52'	50'	48'	46'
2/7	3½	1°59'	1°54'	1°49'	1°44'	1°36'	1°29'	1°23'	1°18'	1°14'	1° 9'	1° 6'	1° 3'	1° 1'	57'	54'	52'
1/3	3	2°19'	2°13'	2° 7'	2° 2'	1°52'	1°44'	1°37'	1°31'	1°26'	1°21'	1°17'	1°13'	1° 9'	1° 6'	1° 3'	1° 1'
4/11	2¾	2°31'	2°25'	2°18'	2°13'	2° 2'	1°54'	1°46'	1°39'	1°34'	1°28'	1°24'	1°20'	1°16'	1°12'	1° 9'	1° 6'
3/8	2⅔	2°36'	2°29'	2°23'	2°17'	2° 6'	1°57'	1°49'	1°43'	1°37'	1°31'	1°26'	1°22'	1°18'	1°15'	1°11'	1° 8'
2/5	2½	2°47'	2°39'	2°32'	2°26'	2°14'	2° 5'	1°57'	1°49'	1°43'	1°37'	1°32'	1°28'	1°23'	1°20'	1°16'	1°13'
4/9	2¼	3° 5'	2°57'	2°49'	2°42'	2°30'	2°19'	2°10'	2° 2'	1°54'	1°48'	1°42'	1°37'	1°33'	1°28'	1°24'	1°21'
1/2	2	3°28'	3°19'	3°10'	3° 2'	2°48'	2°36'	2°26'	2°17'	2° 9'	2° 2'	1°55'	1°49'	1°44'	1°39'	1°35'	1°31'
4/7	1¾	3°58'	3°47'	3°37'	3°28'	3°12'	2°59'	2°47'	2°36'	2°27'	2°19'	2°12'	2° 5'	1°59'	1°54'	1°49'	1°44'
3/5	1⅔	4°37'	4°25'	4°13'	4° 3'	3°44'	3°28'	3°14'	3° 2'	2°52'	2°42'	2°33'	2°26'	2°19'	2°13'	2° 7'	2° 1'
2/3	1½	5°12'	4°58'	4°45'	4°33'	4°12'	3°54'	3°39'	3°25'	3°13'	3° 2'	2°53'	2°44'	2°36'	2°29'	2°23'	2°17'
4/5	1¼	5°32'	5°17'	5° 4'	4°51'	4°20'	4°10'	3°53'	3°39'	3°26'	3°14'	3° 4'	2°55'	2°47'	2°39'	2°32'	2°26'
1	1	6°55'	6°36'	6°19'	6° 3'	5°36'	5°12'	4°51'	4°33'	4°17'	4° 3'	3°50'	3°39'	3°28'	3°19'	3°10'	3° 2'
1⅓	¾			8°24'	8° 3'	7°26'	6°54'	6°27'	6° 4'	5°42'	5°23'	5° 6'	4°51'	4°37'	4°25'	4°13'	4° 2'
1½	⅔				9° 3'	8°22'	7°46'	7°15'	6°49'	6°26'	6° 4'	6°44'	5°27'	5°12'	4°58'	4°45'	4°33'

WORM AND WORM GEAR TOLERANCES

The standard practice adopted by the American Gear Manufacturers Association, but subject to periodic revisions, is intended to form a practical basis upon which gears can be manufactured, inspected, sold, or purchased, although it is not necessarily a rigid specification. It is emphasized that ultimate performance is the final criterion in the acceptance or rejection of gears, regardless of whether they meet arbitrary tolerances. In other words, if gears run smoothly and carry their rated load without breakage or appreciable wear, they will be acceptable for many applications. But when gears fail to perform satisfactorily, definite inspection methods and tolerances are invaluable in locating the cause.

An important consideration is that of the relation of cost to accuracy. Production of gears to the closer tolerances always costs more. In some instances stipulation of the closest tolerances when they are not needed may result in a cost several times what it should be.

Profile errors of worm gear teeth cannot be measured directly because of the change in pressure angle across the face of the gear. So reliance is placed on observation of contact with a master worm or with a mating worm. This places responsibility on the judgment of the inspector.

The pitch range considered is from $\frac{1}{8}$ to 4 axial pitch, arranged in geometrical progression, such as $\frac{1}{8}$, $\frac{1}{4}$, $\frac{1}{2}$, 1, 2 and 4. Tolerances for other pitches may be interpolated. The types of errors considered are runout, pitch error, accumulated error, and required initial area of contact.

Pitch Error

Pitch error of a worm is the maximum difference between any two successive tooth-to-tooth readings in an axial plane between corresponding sides of adjacent teeth. It refers particularly to multiple-thread worms because it indicates the spacing error between successive threads.

In checking pitch errors of multiple-thread worms, an axial plane has been selected as the plane of measurement. Readings may be taken directly in this plane if the lead angle is low, but at higher angles it is preferable to set the indicator and finger to read in a plane normal to the threads, and to convert the readings to an axial plane for purposes of comparison and standardization by dividing by the cosine of the lead angle.

Another method involves the use of master gage blocks to measure directly from one tooth to another in an axial plane.

Pitch error of a worm gear is the maximum difference between any two successive tooth-to-tooth readings taken in the plane of rotation at the pitch circle between corresponding sides of adjacent teeth.

Profile Error

Profile error of a worm tooth is the difference between the highest and lowest readings of a dial indicator moving along a path repre-

TABLE 28a.—WORM INSPECTION TOLERANCES*

Class	Axial Pitch, in Inches	Runout of P. D. Total Indicator Reading					Pitch Error in Axial Plane Multiple Threads Only					Profile Error Total Variation Not Plus and Minus, Lead Angle			Lead Error Total Variation per Convolution, Lead Angle		Lead Error Total Variation per Length of Worm, Lead Angle		
Pitch Diameter		¾	1½	3	6	12	¾	1½	3	6	12	0 to 15 Degree	15 to 30 Degree	30 to 45 Degree	0 to 15 Degree	15 to 30 Degree	0 to 15 Degree	15 to 30 Degree	30 to 45 Degree
Precision High-Speed over 1,000 Ft. per Min. Worm Speed	1	..	..	8	8	10	..	..	5	5	8	4	6	8	5	10	10	12	14
	½	..	5	8	8	10	..	5	5	5	8	3	5	7	5	9	8	10	12
	¼	5	5	8	..	..	5	5	5	..	..	3	4	5	4	7	6	8	10
	⅛	5	5	..	..	..	5	5	..	..	..	2	3	4	3	5	5	6	7
Commercial High-Speed up to 1,000 Ft. per Min. Worm Speed	2	..	..	..	15	..	..	..	..	12	..	8	10	12	15	20	18	20	24
	1	..	..	12	12	15	..	..	8	8	12	6	8	10	7	12	14	16	18
	½	..	8	12	12	15	..	8	8	8	12	5	7	9	7	11	12	14	16
	¼	8	8	12	..	..	8	8	8	..	..	5	6	7	6	9	10	12	14
	⅛	8	8	..	..	..	8	8	..	..	..	4	5	6	5	7	9	10	11
Commercial Medium-Speed up to 200 Ft. per Min. Worm Speed	2	..	..	..	20	20	..	..	..	15	15	10	12	14	17	22	23	25	30
	1	..	..	15	15	20	..	..	12	12	15	8	10	12	9	15	19	21	23
	½	..	12	15	15	20	..	12	12	12	15	7	9	11	9	14	17	19	21
	¼	10	12	15	..	..	12	12	12	..	..	7	8	9	8	12	15	17	19
	⅛	10	12	..	..	..	12	12	..	..	..	6	7	8	7	10	14	15	16
Low-Speed up to 40 Ft. per Min. Worm Speed	4	..	..	..	..	80	..	..	..	..	25	30	40	45	40	80	80	100	120
	2	..	..	..	50	60	..	..	..	18	20	13	15	17	25	35	35	40	45
	1	..	..	40	50	60	..	..	18	18	20	11	13	15	15	22	28	32	35
	½	..	30	40	50	60	..	15	18	18	20	10	12	14	15	20	25	28	32
	¼	30	30	40	..	..	15	15	15	..	..	10	11	12	12	18	22	25	28
	⅛	30	30	..	..	..	15	15	..	..	..	9	10	11	11	15	20	22	24

* All readings in ten-thousandths of an inch.

senting the desired tooth form. It may be measured in an axial or normal plane depending upon the basic tooth form selected.

A considerable departure in form may be acceptable on a worm, provided a corresponding departure is present on the mating worm gear, as indicated by the area of initial tooth contact. Frequently, the form of the worm or the worm gear hob teeth are intentionally modified with respect to each other to concentrate the tooth contact away from the top and bottom of the teeth. This should be given consideration in applying the profile tolerances, because obviously if there is a satisfactory contact between a worm and gear the profile error may be ignored.

Profile error is substantially independent of worm diameter.

Lead Error

Lead error of a worm is expressed either as the total variation in lead for one convolution, or in the total length of the worm. In the latter case it is assumed that the worm is a reasonable amount longer than the minimum necessary to attain proper length of contact, in accordance with good design.

Accumulated Error

Accumulated error of a worm gear is the maximum accumulation of pitch errors obtained by algebraic addition of tooth-to-tooth pitch errors.

In deriving the accumulated error, the tooth-to-tooth pitch errors must be corrected with reference to the true pitch.

Unless otherwise specified, accumulated error is checked over the entire 360 degrees, and expressed as the maximum error between any two teeth. In some cases it is measured only for one-half or one-third of a circle, and occasionally tolerances are set for accumulation over any three or four adjacent teeth.

Required Initial Area of Contact

The initial area of contact between a worm and worm gear is determined by operating the set at proper center distance, and side and angular relations, under average operating loads for a short time, then observing the contact on all the worm gear teeth. If means are not available for operating a worm and worm gear under load, the contact area must be judged by hand testing. In either case, the percentage of contact is a matter of judgment by eye, because precise methods of measuring such areas are not available.

If the set is to operate in one direction only, then the contact need be checked only on the one set of profiles.

TABLE 28b.—WORM GEAR INSPECTION TOLERANCES*

Class	C. P. Inches	Runout of P. D., Total Indicator Reading								Pitch Error Measured on Pitch Circle in Plane of Rotation								Accumulated Error between Any Two Teeth Exclusive of Runout Effect								Required Minimum Initial Area of Contact, Per Cent
P. D.		¾	1½	3	6	12	25	50	100	¾	1½	3	6	12	25	50	100	¾	1½	3	6	12	25	50	100	
Precision High-Speed over 1,000 Ft. per Min. Worm Speed	1	..	..	..	10	10	12	14	16	..	..	..	5	5	5	6	6	..	..	..	10	10	12	20	30	50
	½	..	..	10	10	10	12	14	16	..	..	4	4	4	5	5	5	..	..	10	10	10	12	20	30	
	¼	..	10	10	10	10	12	..	...	...	2½	3	3	3	4	..	..	.	10	10	10	10	12	20	30	
	⅛	10	10	10	..	..	..	..	...	2½	2½	3	..	..	..	..	..	10	10	10	..	..	..	..	..	
Commercial High-Speed up to 1,000 Ft per Min. Worm Speed	2	..	..	..	..	20	25	..	...	...	...	...	..	9	9	..	..	..	..	..	..	20	27	..	..	40
	1	..	..	..	20	20	25	25	30	...	...	...	7	7	7	8	8	..	..	..	15	15	15	35	55	
	½	..	..	10	15	20	25	25	30	...	...	6	6	6	6	7	7	..	..	15	15	15	15	30	45	
	¼	..	10	10	15	20	25	..	...	...	3½	4	4	4	4	..	..	..	15	15	15	15	15	..	..	
	⅛	10	10	10	..	..	..	..	...	3	3	3½	..	..	..	..	..	15	15	15	..	..	..	..	..	
Commercial Medium-Speed up to 200 Ft. per Min. Worm Speed	2	..	..	..	..	25	30	35	40	...	...	...	..	15	20	25	30									30
	1	..	..	..	20	25	30	35	40	...	...	...	10	12	12	15	20									
	½	..	..	20	20	25	30	35	...	...	...	8	8	10	10	12	..									
	¼	..	15	20	20	25	30	..	...	...	7	7	7	8	8	..	..									
	⅛	15	15	20	..	..	..	..	...	5	5	6	..	..	..	..	..									
Low-Speed up to 40 Ft. per Min. Worm Speed	4	..	..	..	..	..	90	90	100	...	...	...	..	..	60	70	80									20
	2	..	..	..	..	60	80	80	90	...	...	...	..	35	40	50	60									
	1	..	..	..	60	60	80	80	90	...	...	...	30	35	35	40	50									
	½	..	..	50	60	60	80	80	...	...	...	25	25	30	30	35	..									
	¼	..	30	50	60	60	80	..	...	...	20	20	20	25	25	..	..									
	⅛	30	30	50	..	..	..	..	...	15	15	20	..	..	..	..	..									

* All readings in ten-thousandths of an inch.

LINK-BELT SILENT-CHAIN DRIVE DATA

Link-Belt silent chains may be run with equal efficiency in either direction and are reversible.

Where exceptionally quiet drives are required, use wheels with 23 or more teeth, short pitch, wide chain; also recommended are encasing and running in oil.

Most practical and economic chain speeds are between 1,000 and 1,600 feet per minute.

For drives under 1,000 feet per minute use roller chain; for drives over 1,600 feet per minute, submit your problem to the makers.

Minimum center distance equals four-fifths difference in diameter of wheels.

Speed ratios up to 15:1 are economical and practical. Higher ratios are possible, but a double reduction or speed reducer is more desirable for large ratios.

Lubrication of chain is essential; always use a good grade of oil. Do not use grease. When run in oil bath the lowest point of the chain, while operating, should be immersed about ¼ inch.

Duplex or "back type" silent chain is arranged for operating sprocket wheels on both faces of the chain, permitting the operation of wheels either clock- or counterclockwise in the same drive.

Any number of sprockets may be employed on either side of a single duplex chain. It is recommended that not less than a 90-degree arc of contact be provided for.

The automatic adjustment and vibration damper maintains the correct operating tension on a chain drive, creating an ultra-smooth operation. It is especially desirable on fixed-center drives with the duplex chain.

Recommendations for Design

It is desirable to have an even number of links in the chain and an odd number of teeth in the sprockets.

Use sprockets with more than 130 teeth only when necessary for large speed ratios.

Adjustable centers are desirable but not always necessary.

For very short centers without adjustment the pulling strand should be on top.

For pulsating loads, such as compressors, spring sprockets are advisable unless sufficient flywheel is provided to maintain fairly uniform rotation.

For occasional sudden overloads, shear pin sprockets should be used to safeguard the drive and all the machinery.

Approximate weight of chain per foot per inch of width equals two times the pitch.

TABLE 29.—LINK-BELT SILENT-CHAIN DRIVE DATA

The data given is for usual range of silent chain applications; when specifications are above or below tables consult nearest maker's representative. When horsepower required is greater than may be accomplished by given pitch and width specified for correct speeds, satisfactory result can be obtained by employing multiple strands.

Pitches, In.	3/8	1/2	5/8	3/4	1	1¼	1½	2	2½
Minimum recommended number of teeth, Drive R	17	17	17	17	17	17	17	19	19
Minimum recommended number of teeth, Drive N	17	19	19	21	21	23	23	25	25
Maximum recommended number of teeth	387	387	387	387	387	387	215	215	215
Pitch diameter (in.) = number of teeth times	0.1193	0.1590	0.1989	0.2387	0.3183	0.3979	0.4775	0.6366	0.7958
Under-rim diameter-pitch diameter (in.) minus	1.	1.13	1.38	1.75	2.25	2.75	3.25	4.13	5.00
Maximum radius over keyseat of steel pinions = pitch radius (in.) minus	0.40	0.50	0.65	0.80	1.00	1.30	1.50	2.00	2.50
Radius over chain = pitch radius (in.) plus	0.187	0.234	0.281	0.343	0.453	0.578	0.671	0.843	1.250
Maximum r.p.m. of minimum recommended sprocket	5,000	3,000	2,000	1,500	1,200	1,000	800	500	300
C = weight constant (armed wheels)	0.09	0.15	0.25	0.30	0.50	0.80	1.2	2.0	2.4
K = weight constant (solid pinions)	0.003	0.005	0.007	0.010	0.017	0.026	0.035	0.070	0.100
Minimum width (in.) chain recommended (nominal)	7/16	9/16	1	1	2	3	3	4	6
Maximum width (in.) chain recommended (nominal)	4	6	8	12	14	18	24	24	30
Horsepower per inch width employing minimum pinion recommended at:									
1,000 ft. per minute	3.1	4.1	5.1	6.1	8.1	11.5	13.9	19.4	24.3
1,300 ft. per minute	3.5	4.6	5.8	7.0	9.3	13.6	16.3	23.5	28.0
1,600 ft. per minute	3.9	5.0	6.4	7.7	9.9	15.3	18.3	28.0	32.0
Overall width of chain-nominal width (in.) plus	3/16	3/16	3/16	3/16	1/4	5/16	3/8	3/8	9/16
Approximate weight of chain 1 in. wide and 1 ft. long (lb.)	0.9	1.06	1.25	1.25	1.64	2.45	3.0	3.4	5.0

Approximate weight of armed wheels = $N \times W \times C$.
Approximate weight of solid pinions = $(P \text{ plus } W) \times N^2 \times K$.

N = number of teeth.
W = width of face.
P = pitch.

* For complete horsepower and speed tables consult Link-belt Company.

TABLE 30.—MORSE CHAIN DRIVES

The distinctive feature of construction is the rocker joint which provides rolling instead of friction in the joint. While 1,500 ft. minimum is common, much higher velocities are good practice under favorable conditions.

DATA TO BE USED IN DESIGN OF MORSE CHAIN DRIVES
With Small Sprocket Driver

Pitch, In.	Normal r.p.m.*	Normal Tension for 1 In. Wide*	Minimum Number Teeth Driver	Desirable Maximum Number Teeth Driver	Minimum Desirable Number Teeth Driver	Minimum Desirable Center Distance In.	Minimum Number Teeth*	Normal Tension for 1 In. Wide*
$\frac{3}{8}$	4,000	75	13	75	15–17	6	13	75
$\frac{1}{2}$	2,400	100	13	99	15–17	8	17	80
$\frac{5}{8}$	1,800	125	13	109	17–21	14	17	100
$\frac{3}{4}$	1,400	150	13	115	17–21	18	21	120
0.9	1,100	185	15	125	17–23	21	23	150
1	1,000	205	15	125	17–23	24	23	165
1.2	800	250	15	129	17–23	30	23	200
$1\frac{1}{2}$	600	335	17	129	17–27	36	23	270
2	400	560	17	129	17–31	48	25	450
3	250	935	17	131	19–31	66	27	750

* Under favorable conditions these figures can be exceeded somewhat, and under unfavorable conditions they must be reduced.

TABLE 31.—MORSE CHAIN AND SPROCKET DATA

Pitch		3/8	1/2	5/8	3/4	9/10	1 3/10	1 1/2	2	3
Minimum number of teeth:	Small sprocket driver	13	13	13	13	15	15	17	17	17
	Small sprocket driven	13	17	17	21	25	29	29	31	35
Desirable number of teeth in driver sprockets		15–17	15–17	17–21	17–21	17–23	17–23	17–27	17–31	19–31
Maximum number of teeth in sprockets (see note 3)		75	99	109	115	125	129	129	129	131
Desirable number of teeth in driven sprockets		35–45	55–75	55–75	55–85	55–95	55–105	55–115	55–115	55–115
To find pitch diameter of wheel multiply number of teeth by (inches)		.1193	.159	.199	.239	.2865	.382	.477	.636	.955
Addendum—for outside diameter of sprockets 33 to 130T (see note 1) (inches)		None	.05	.06	.075	.09	.12	.15	.20	.30
Maximum R.P.M.		6000	2400	1800	1200	1100	800	600	400	250
Tension per inch width chain, pounds	Small sprocket driver	60	80	100	120	150	200	270	450	750
	Small sprocket driven	60	65	80	95	120	160	210	350	600
Radial clearance beyond tooth required for chain (inches)		.375	.50	.62	.75	.90	1.2	1.5	2.	3.
Approximate weight of chain per inch width, 1 foot long (pounds)		.75	1.00	1.20	1.50	1.80	2.50	3.	4.	6.
C Constants for solid pinions		.003	.0045	.0063	.009	.013	.023	.035	.058	.145
C Constants for armed sprockets		.10	.16	.25	.35	.45	.7	1.	2.	4.

Approximate Weight for Solid Pinions and Armed Sprockets

When T = Number of teeth. F = Face in inches. C = Constant in pounds per inch in face per tooth. $T^2 \times F \times C$ = weight of armed sprocket. Add 25 per cent. if split; add 50 per cent. if spring sprocket and split. For solid pinions: $C \times T^2 \times (F + 1)$ = Weight.

STANDARD ROLLER CHAIN DIMENSIONS

Roller diameters are approximately $\frac{5}{8}$ P.

Widths.—The width is defined as the minimum distance between the inside plates. In the wide series the width is the nearest binary fraction to $\frac{5}{8}$ P. In the narrow series it is the nearest binary fraction to 0.41 P. The narrow chains are seldom used and are not recommended except for unusual cases.

Pin diameters are approximately $\frac{5}{16}$ P or one-half of the roller diameter.

Thickness of inside plates for the standard series is approximately $\frac{1}{8}$ P.

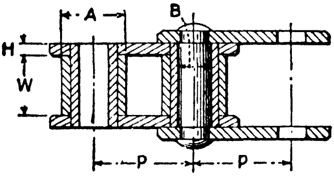


TABLE 32.—GENERAL CHAIN DIMENSIONS

		Standard Series						Extra Heavy Series
Pitch P	Roller Diameter A	Width W	Pin Diameter B	Thickness of Inside Plate H	Test Load, Lb.	Measuring Load, Lb.	Standard Chain No.	Thickness of Inside Plate H
$\frac{3}{8}$	0.200	$\frac{3}{16}$	0.141	0.050	555	17	35N	
$\frac{1}{2}$	$\frac{5}{16}$	$\frac{5}{16}$	0.156	0.060	740	23	40	
$\frac{5}{8}$	0.400	$\frac{3}{8}$	0.200	0.080	1,400	44	50	
$\frac{3}{4}$	$\frac{15}{32}$	$\frac{1}{2}$	0.234	0.094	2,018	63	60	0.125
1	$\frac{5}{8}$	$\frac{5}{8}$	0.312	0.125	3,820	119	80	0.156
$1\frac{1}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	0.375	0.156	5,626	176	100	0.187
$1\frac{1}{2}$	$\frac{7}{8}$	1	0.437	0.187	7,760	242	120	0.219
$1\frac{3}{4}$	1	1	0.500	0.219	10,220	319	140	0.250
2	$1\frac{1}{8}$	$1\frac{1}{4}$	0.562	0.250	13,008	406	160	0.281
$2\frac{1}{2}$	$1\frac{9}{16}$	$1\frac{1}{2}$	0.781	0.312	25,340	792	200	0.375
3	1.90	$1\frac{7}{8}$	0.937	0.375	36,634	1,145	240	0.500

P.D. of sprocket $= P \div \sin \frac{180°}{T}$, where P is the pitch, and T is the number of teeth.

Bottom diameter of sprocket = P.D. − roller diameter.

O.D. of sprocket (minimum) $= P\left(0.6 + \cot \frac{180°}{T}\right)$.

Table 33.—Standard Pitch Diameters and Outside Diameters of Sprockets, 1-Inch Pitch Roller Chain

For other pitches multiply these values by the pitch.

To obtain bottom diameters subtract diameter of chain roller from pitch diameter.

(All Dimensions in Inches)

No. Teeth	Pitch Diameter	Outside Diameter	No. Teeth	Pitch Diameter	Outside Diameter	No. Teeth	Pitch Diameter	Outside Diameter
6	2.0000	2.332	46	14.6536	15.219	86	27.3807	27.962
7	2.3048	2.677	47	14.9717	15.538	87	27.6989	28.281
8	2.6131	3.014	48	15.2898	15.857	88	28.0171	28.599
9	2.9238	3.347	49	15.6079	16.176	89	28.3354	29.918
10	3.2361	3.678	50	15.9260	16.495	90	28.6536	29.236
11	3.5495	4.006	51	16.2441	16.813	91	28.9718	29.554
12	3.8637	4.332	52	16.5619	17.132	92	29.2900	29.873
13	4.1785	4.657	53	16.8803	17.451	93	29.6082	30.191
14	4.4940	4.982	54	17.1984	17.769	94	29.9264	30.510
15	4.8097	5.305	55	17.5166	18.088	95	30.2446	30.828
16	5.1259	5.627	56	17.8347	18.406	96	30.5628	31.146
17	5.4423	5.950	57	18.1529	18.725	97	30.8811	31.465
18	5.7588	6.271	58	18.4710	19.044	98	31.1994	31.783
19	6.0756	6.593	59	18.7892	19.363	99	31.5177	32.102
20	6.3925	6.914	60	19.1073	19.681	100	31.8360	32.420
21	6.7095	7.235	61	19.4255	20.000	101	32.1543	32.739
22	7.0266	7.555	62	19.7437	20.318	102	32.4726	33.057
23	7.3439	7.875	63	20.0618	20.637	103	32.7909	33.376
24	7.6613	8.196	64	20.3800	20.955	104	33.1091	33.694
25	7.9787	8.516	65	20.6982	21.274	105	33.4274	34.012
26	8.2962	8.836	66	21.0164	21.593	106	33.7457	34.331
27	8.6138	9.156	67	21.3346	21.911	107	34.0640	34.649
28	8.9315	9.475	68	21.6528	22.230	108	34.3823	34.968
29	9.2491	9.795	69	21.9710	22.548	109	34.7006	35.286
30	9.5668	10.114	70	22.2892	22.867	110	35.0189	35.605
31	9.8845	10.434	71	22.6074	23.185	111	35.3371	35.923
32	10.2023	10.753	72	22.9256	23.504	112	35.655	36.241
33	10.5201	11.072	73	23.2438	23.822	113	35.974	36.560
34	10.8380	11.392	74	23.5620	24.141	114	36.292	36.878
35	11.1558	11.711	75	23.8802	24.459	115	36.610	37.197
36	11.4737	12.030	76	24.1984	24.778	116	36.929	37.515
37	11.7917	12.349	77	24.5166	25.096	117	37.247	37.833
38	12.1096	12.668	78	24.8349	25.415	118	37.565	38.152
39	12.4275	12.987	79	25.1531	25.733	119	37.883	38.470
40	12.7455	13.306	80	25.4713	26.052	120	38.201	38.788
41	13.0635	13.625	81	25.7895	26.370	121	38.519	39 106
42	13.3815	13.944	82	26.1078	26.689	122	38.837	39.425
43	13.6995	14.263	83	26.4260	27.007	123	39.156	39.743
44	14.0175	14.582	84	26.7443	27.326	124	39.475	40.062
45	14.3356	14.901	85	27.0625	27.644	125	39.794	40.381

Conversion of Number of Pitches to Inches and Feet

In ordering chains, the exact length, including connecting link, should be specified in feet and inches, as well as in pitches.

To convert pitches to feet, multiply the number of rollers by the pitch and divide by 12. To convert feet to pitches, multiply by 12 and divide by the pitch.

TABLE 34.—RECOMMENDED SIZES OF CUTTERS FOR BLOCK-CHAIN SPROCKETS
(All Dimensions in Inches.)

Pitch of Chain	Block End Diam.	Pitch of Block	Cutter Diam.	Bore	Keyway	Cutter Width					
						6*T*	7–8*T*	9–11*T*	12–17*T*	18–34*T*	35*T* up
1	0.325	0.400	3	1	5/32 × 5/64	1 3/16	1 5/32	1 5/32	1 1/8	1 1/8	1 3/32
1 1/2	0.531	0.563	4	1 1/4	3/16 × 3/32	1 23/32	1 3/4	1 3/4	1 11/16	1 11/16	1 5/8

RECOMMENDED CUTTER SIZES FOR ROLLER-CHAIN SPROCKETS
(All Dimensions in Inches)

Pitch	Roll Diam.	Cutter Diameter, Minimum						Cutter Width, Minimum						Bore	Keyway
		6*T*	7–8*T*	9–11*T*	12–17*T*	18–34*T*	35*T* and over	6*T*	7–8*T*	9–11*T*	12–17*T*	18–34*T*	35*T* and over		
3/8	0.200	2 3/4	2 3/4	2 3/4	2 3/4	2 3/4	2 3/4	15/32	15/32	15/32	7/16	7/16	13/32	1	5/32 × 5/64
1/2 to 5/8	0.313	3	3	3 1/8	3 1/8	3 1/8	3 1/8	3/4	3/4	3/4	3/4	23/32	11/16	1	5/32 × 5/64
5/8	0.400	3 1/8	3 1/8	3 1/4	3 1/4	3 1/4	3 1/4	3/4	3/4	3/4	3/4	23/32	11/16	1	5/32 × 5/64
3/4	0.469	3 1/4	3 1/4	3 3/8	3 3/8	3 3/8	3 3/8	29/32	29/32	29/32	7/8	27/32	13/16	1	5/32 × 5/64
1	0.563	3 3/4	3 7/8	3 7/8	4	4	4	1 1/4	1 1/4	1 1/16	1 5/32	1 1/8	1 3/32	1 1/4	3/16 × 3/32
1 to 1 1/4	0.625	3 7/8	4	4 1/8	4 1/8	4 1/4	4 1/4	1 1/2	1 1/2	1 15/32	1 15/32	1 13/32	1 11/32	1 1/4	3/16 × 3/32
1 1/4 to 1 1/2	0.750	4 1/4	4 3/8	4 1/2	4 1/2	4 7/8	4 5/8	1 11/16	1 11/16	1 19/32	1 5/8	1 9/16	1 1/2	1 1/4	3/16 × 3/32
1 1/2	0.875	4 3/4	4 7/8	5	5	5 1/8	5 1/8	1 13/16	1 13/16	1 25/32	1 3/4	1 11/16	1 5/8	1 1/2	5/16 × 5/32
1 3/4	1.000	5	5 1/8	5 1/4	5 3/8	5 1/2	5 1/2	2 3/32	2 3/32	2 1/16	2 1/32	1 31/32	1 7/8	1 1/2	5/16 × 5/32
2	1.125	5 3/8	5 1/2	5 5/8	5 3/4	5 7/8	5 7/8	2 13/32	2 13/32	2 3/8	2 5/16	2 1/4	2 5/32	1 1/2	5/16 × 5/32
2 1/2	1.550	6 3/8	6 5/8	6 3/4	6 7/8	7	7 1/8	3	3	2 15/16	2 23/32	2 5/8	2 9/16	1 3/4	3/8 × 3/16
3	1.900	7 1/2	7 3/4	7 7/8	8	8	8 1/4	3 19/32	3 19/32	3 17/32	3 15/32	3 13/32	3 7/32	2	1/2 × 1/4

MAXIMUM SPROCKET SPEEDS AND CHAIN VELOCITIES

On May 4, 1935, the A.G.M.A. approved the maximum sprocket speeds (Table 35) and maximum chain velocities for various numbers of teeth in the smaller sprocket. Hitherto the maximum chain velocity has been considered to be about 1,600 feet per minute, regardless of the weight of the chain or the number of teeth in the sprocket. Also, the maximum revolutions per minute has been taken as

$$\text{Max. r.p.m.} = \frac{1{,}920}{P}\sqrt{\frac{A}{W_F P}},$$

regardless of the number of impacts of the roller per minute. P = pitch, A = projected area of the roller, and W_F = weight per foot of chain.

Observations of many chain drives have shown that higher chain velocities are permissible under certain conditions and that lower sprocket speeds should be used under other conditions. The figures in the table are computed from three formulas, each expressing a separate limiting condition affecting sprocket speeds and chain velocities.

The upper figure in each square is the maximum number of revolutions per minute, and the lower figure is the corresponding maximum chain velocity which is found by multiplying the maximum number of revolutions per minute by the product of the number of teeth and the pitch, and then dividing by 12. Figures in the upper left-hand block are calculated from the formula:

$$\text{Max. r.p.m.} = \frac{2{,}000}{P}\sqrt[3]{\frac{A}{W_F}},$$

based on the theory that the allowable energy of roller impact per tooth per minute should not exceed a certain maximum. P = pitch; A = projected area of the roller, and W_F = weight per foot of chain.

Figures in the lower block are calculated from the formula:

$$\text{Max. r.p.m.}$$

based on the theory that the allowable energy of a single roller impact should not exceed a certain maximum.

Figures in the upper right-hand block are calculated from the formula:

$$\text{Max. r.p.m.}$$

based on the theory that the maximum allowable centrifugal force for one chain link is proportional to the projected area of the roller. N = number of teeth in smaller sprocket.

The tabulated figures are in each case the least of those yielded by the three formulas.

Examination of the table will show that, for chain No. 41 running over sprockets with not less than 54 teeth, the chain velocity can be as high as 3,195 feet per minute, while a 2½-inch pitch chain over a 9-tooth wheel should not run at a velocity exceeding 450 feet per minute. Also, it will be seen that in the case of chain No. 50, operating over a 15-tooth sprocket, the maximum revolutions per minute is 1,900, whereas a 54-tooth sprocket has a permissible speed of only 1,028 revolutions per minute.

Moving-Picture Projector Sprockets

Both cameras and projectors for moving pictures require great accuracy in the gearing used. The standards of the Society of Motion Picture Engineers for 8-, 16- and 35-millimeter projector sprockets are given, together with the tolerances permitted, in Tables 36, 37, and 38.

The standard speed for silent films is 16 frames per second, and for sound pictures, 24 per second. In the sound pictures the distance between the center of the picture and the corresponding sound is 20 frames on the 35-millimeter film, and 26 frames on the 16-millimeter film, this being the spacing between the lens and the sound-reproducing apparatus.

TABLE 35.—MAXIMUM REVOLUTIONS PER MINUTE AND MAXIMUM CHAIN VELOCITIES FOR AMERICAN STANDARD ROLLER CHAINS

Upper Figures Are Maximum Revolutions per Minute; Lower Figures Are Maximum Chain Velocities in Feet per Minute

Chain No.	Pitch	Roll Diameter	Number of Teeth in Smaller Sprocket															
			7	9	11	13	14	15	16	17	20	24	28	32	37	48	54	62
35N	3/8	0.200	3043 667	3043 857	3043 1048	3043 1238	2935 1284	2835 1330	2744 1373	2662 1414	2455 1524	2240 1680	2073 1817	1940 1940	1805 2088	1585 2377	1495 2520	1395 2700
41	1/2	0.306	2654 772	2654 993	2654 1213	2654 1434	2654 1545	2654 1655	2580 1718	2500 1770	2306 1920	2106 2100	1950 2275	1823 2428	1695 2612	1488 2973	1407 3195	1310 3380
40	1/2	5/16	2517 732	2517 942	2517 1150	2517 1360	2517 1465	2460 1534	2381 1585	2310 1634	2130 1770	1945 1940	1800 2100	1685 2240	1567 2411	1375 2748	1298 2910	1210 3120
50	5/8	0.400	1900 692	1900 890	1900 1089	1900 1287	1900 1384	1900 1480	1885 1570	1830 1620	1688 1760	1542 1925	1426 2080	1335 2222	1241 2390	1089 2722	1028 2885	958 3095
60	3/4	15/32	1500 657	1500 844	1500 1032	1500 1220	1500 1313	1500 1407	1500 1500	1500 1584	1392 1740	1270 1905	1176 2060	1100 2200	1023 2368	898 2697	848 2860	791 3061
80	1	5/8	940 549	940 705	940 862	940 1019	940 1097	940 1173	940 1254	940 1330	940 1567	940 1880	885 2032	828 2195	771 2360	677 2690	638 2850	594 3055
100	1 1/4	3/4	645 470	645 604	645 738	645 872	645 940	645 1010	645 1075	645 1145	645 1347	645 1612	645 1880	639 2131	593 2292	522 2611	492 2768	459 2968
120	1 1/2	7/8	520 455	520 585	520 715	520 845	520 910	520 975	520 1040	520 1104	520 1300	520 1560	520 1820	520 2080	515 2385	453 2715	427 2878	398 3085
140	1 3/4	1	370 378	370 486	370 594	370 702	370 756	370 810	370 864	370 917	370 1080	370 1296	370 1510	370 1728	370 1996	370 2590	364 2851	339 3060
160	2	1 1/8	325 379	325 487	325 595	325 704	325 758	325 813	325 867	325 922	325 1083	325 1300	325 1516	325 1734	325 2003	325 2600	301 2708	281 2905
200	2 1/2	1 9/16	240 350	240 450	240 550	240 650	240 700	240 750	240 800	240 850	240 1000	240 1200	240 1400	240 1600	240 1850	240 2400	240 2700	229 2955

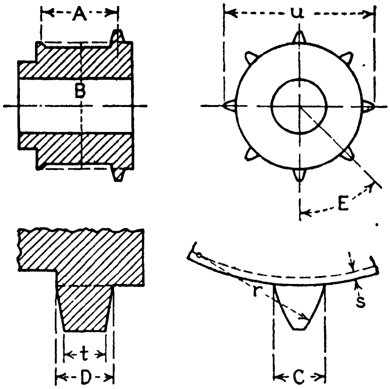
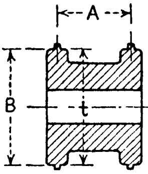
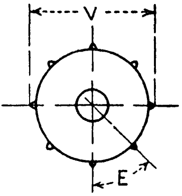
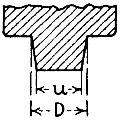


TABLE 36.—AMERICAN STANDARD FOR 8-MILLIMETER FILM 8-Tooth Projector Sprockets

	Millimeters	Inch Equivalents
A	5.72 ± 0.03	0.225 ± 0.001
B	9.42 + 0.00 − 0.05	0.371 + 0.000 − 0.002
C	1.02 + 0.00 − 0.05	0.040 + 0.000 − 0.002
D	1.14 + 0.08 − 0.00	0.045 + 0.003 − 0.000
E	45°0′ ± 0.5′	
Recommended Practice		
r	2.54	0.100
s	0.13	0.005
t	0.51	0.020
u	11.33	0.450







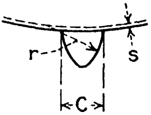


TABLE 37.—AMERICAN STANDARD FOR 16-MILLIMETER FILM Projector Sprockets

	N	*B*		*E*	Number of Teeth in Mesh							
					3		4		5		6	
					C		*C*		*C*		*C*	
		Mm.	In.		Mm.	In.	Mm.	In.	Mm.	In.	Mm.	In.
Feed	6	14.38	0.566	60°0′ ±0.5′	1.02	0.040						
	8	19.23	0.757	45°0′ ±0.5′	1.02	0.040	0.91	0.036				
	12	28.93	1.139	30°0′ ±0.5′	1.02	0.040	0.91	0.036	0.79	0.031	0.69	0.027
	16	38.63	1.521	22°30′ ±0.5′	1.02	0.040	0.91	0.036	0.79	0.031	0.69	0.027
Take-Up (Holdback)	6	14.15	0.557	60°0′ ±0.5′	1.02	0.040						
	8	18.92	0.745	45°0′ ±0.5′	1.02	0.040	0.91	0.036				
	12	28.50	1.122	30°0′ ±0.5′	1.02	0.040	0.91	0.036	0.79	0.031	0.69	0.027
	16	38.05	1.498	22°30′ ±0.5′	1.02	0.040	0.91	0.036	0.79	0.031	0.69	0.027
Combination	6	14.30	0.563	60°0′ ±0.5′	1.09	0.043						
	8	19.13	0.753	45°0′ ±0.5′	1.09	0.043	1.02	0.040				
	12	28.78	1.133	30°0′ ±0.5′	1.09	0.043	1.02	0.040	0.94	0.037	0.86	0.034
	16	38.43	1.513	22°30′ ±0.5′	1.09	0.043	1.02	0.040	0.94	0.037	0.86	0.034

		Millimeters	Inch Equivalents
For All Sprockets	*A*	12.22 + 0.05 − 0.00	0.481 + 0.002 − 0.000
	D	1.22 + 0.00 − 0.08	0.048 + 0.000 − 0.003
	r	1.27	0.050
	s	0.08	0.003
	t	*B* − 0.3, Max.	*B* − 0.01, Max.
	u	1.00	0.039
	v	*B* + 1.52, Max.	*B* + 0.060, Max.

Notes

N = number of teeth on sprocket.

Tolerance for *B* and *C*, +0.000 to −0.025 millimeter, or +0.000 to −0.001 inch.

Dimensional standards indicated by capital letters.

Recommended practice indicated by lower case letters.

Values of *C* are omitted in cases where the angle of wrap on the sprocket would exceed 180 degrees.

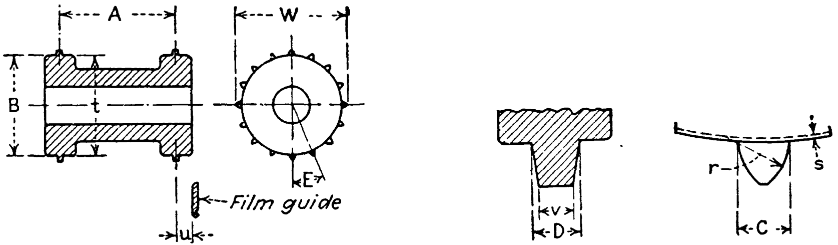


TABLE 38.—AMERICAN STANDARD FOR 35-MILLIMETER FILM
16-Tooth Projector Sprockets

	Feed Sprocket		Intermittent Sprocket		Take-Up (Hold back) Sprocket	
	Millimeters	Inch Equivalents	Millimeters	Inch Equivalents	Millimeters	Inch Equivalents
A	27.36 ± 0.03	1.097 ± 0.001	27.86 ± 0.03	1.097 ± 0.001	27.86 ± 0.03	1.097 ± 0.001
B	24.00 ± 0.03	0.945 ± 0.001	24.00 ± 0.005	0.945 ± 0.0002	23.67 ± 0.03	0.932 ± 0.001
C	1.40 + 0.00 − 0.05	0.055 + 0.000 − 0.002	1.40 + 0.00 − 0.05	0.055 + 0.000 − 0.002	1.40 + 0.00 − 0.05	0.055 + 0.000 − 0.002
D	1.40 ± 0.00 − 0.05	0.055 + 0.000 − 0.002	1.40 + 0.00 − 0.05	0.055 + 0.000 − 0.002	1.40 + 0.00 − 0.05	0.055 + 0.000 − 0.002
E	22°30′ ± 1.5′		22°30′ ± 0.75′*		22°30′ ± 1.5′	
	Recommended Practice					
r	1.96	0.077	1.96	0.077	1.96	0.077
s	0.10	0.004	0.10	0.004	0.10	0.004
t	23.75	0.935	23.75	0.935	23.42	0.922
u	3.53	0.139	3.53	0.139	3.53	0.139
v	1.02	0.040	1.02	0.040	1.02	0.040
w	26.54	1.045	26.54	1.045	26.21	1.032

* The accumulated error between any two teeth not to exceed 4 minutes.

Rack Teeth

Rack teeth are generally cut with a gang of circular gear cutters, or by the Fellows gear-shaping method, in which the rack is fed past the reciprocating cutter at the proper rate to generate the teeth, as with a gear. The Fellows machines have independent motors for each function. The main drive motor is 3 horse-power; table traverse, ½ horse-power; depth of feed, ⅓ horse-power; and the coolant pump, ¼ horse-power. The ram speed varies from 66 to 403 strokes per minute.

Racks are sometimes cut in a regular shaper, using a form tool and suitable means for spacing the distance between the teeth.

Measurement of Racks

In measuring a rack, the distance that a 1.728 inch diameter wire projects above the pitch line of the teeth for a 1 diametral pitch rack is as follows:

Degrees	14½	17½	20	25	30
Inches......	1.2779	1.2463	1.2323	1.2241	1.2316

For any other diametral pitch (p) divide the values by p and use wires $\frac{1.728}{p}$ inches in diameter.

To find the distance the wire projects above the tops of the teeth of a 1p rack subtract 1 from the above values.

SECTION IX

TURNING AND BORING

Turning and boring include some of the most important shop operations, from heavy roughing cuts to the single-point boring now used in much precision work. Single-point tools are being standardized as to both shapes and nomenclature. Cemented carbide tips are also standardized in size and are becoming more economical on much work. Except in extremely heavy work, such as tire turning, standard toolholders and bits are common practice.

SINGLE-POINT TOOLS

The following definitions of single-point tools and their cutting angles were adopted in June, 1938:

Terminology and Definitions—Single-Point Cutting Tools: for Lathes, Planers, Shapers, Turret Lathes, Boring Mills, Etc.

TOOL ELEMENTS

Size.—The size of a tool of square or rectangular section is expressed by giving, in the order named, the width of shank, the height of shank, and the total tool length, in inches, such as ¾ × 1½ × 12 inches. The same method of designation is used for tool bit holders to which is added the size of the bits.

Shank.—The shank is that part of the tool on one end of which the point is formed or the tip or bit is supported. The shank in turn is supported on the tool post of the machine, Figs. 1, 2, and 3 (see American Standard for toolholder shanks and tool-post openings, Sec. XVIII).

Base.—The base is that surface of the shank which bears against the support and takes the tangential pressure of the cut, Figs. 1, 2, and 3.

Heel.—The heel is the edge between the base and the flank immediately below the face, Figs. 1, 2, and 3.

Face.—The face is that surface on which the chip impinges as it is cut from the work.

Point.—The point is all that part of the tool which is shaped to produce the cutting edges and face.

Cutting Edge.—The cutting edge is that portion of the face edge along which the chip is separated from the work. The cutting edge consists usually of the side-cutting edge, the nose radius, and the end-cutting edge, Figs. 1, 2, 4, and 5.

Nose.—The nose is the curve formed by joining the side-cutting and end-cutting edges.

Shape.—The shape of the tool is the contour of the face when viewed in a direction at right angles to the base.

Flank.—The flank of the tool is the surface or surfaces below and adjacent to the cutting edge, Fig. 1.

Neck.—The neck is an extension of the shank of reduced sectional area. A relatively small point, as required in boring, is sometimes attached to the shank by a neck, Fig. 4.

Flat.—The flat is the straight portion of the cutting edge intended to produce a smooth machined surface, Fig. 5.

Chip Breaker or Control.—The chip breaker is an irregularity in the face of a tool, or a separate piece fastened to the tool or toolholder, to cause the chip to break into short sections or curl, Fig. 6.

TYPES OF TOOLS

Ground Tool.—A ground tool is one in which the point is formed on the end of a bar (shank) of tool steel by grinding, Fig. 1.

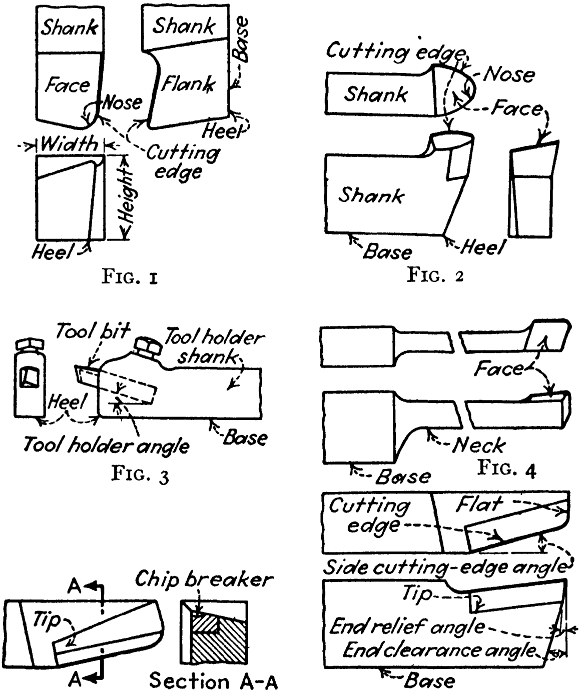


FIG. 1 FIG. 2 FIG. 3 FIG. 4 FIG. 6 FIG. 5

FIGS. 1 to 6.—Single-Point Tools

Forged Tool.—A forged tool is one in which the point is forged roughly to shape on the end of a bar (shank) of tool steel before hardening and grinding, Fig. 2.

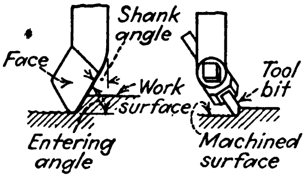
Tipped Tool.—A tipped tool is one with a tip of cutting material, permanently attached to a shank of noncutting material. The tip is ground to form the cutting edges and face of the tool, Figs. 5 and 6.

Curved Cutting-Edge Tool.—A curved cutting-edge tool has variable side-cutting-edge angles, Fig. 2.

Raised-Face Tool.—A raised-face tool is one having its face above the top of the shank. Forged tools, as in Fig. 2, frequently have the face raised above the shank top so that less material need be removed in regrinding the point. The details of forged tools should be shown by drawings.

Bit Tool.—A bit tool is one in which small parts of the tool materials, of square, rectangular, or other section, or forged to special shapes, are held in the end of a holder or shank, Fig. 3.

Toolholder.—A toolholder is a tool shank designed to hold a removable point or tool bit, Fig. 3.



FIGS. 7*a* and 7*b*

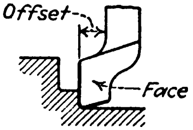


FIG. 8

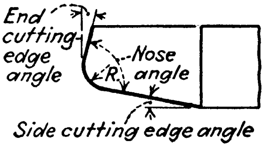


FIG. 10

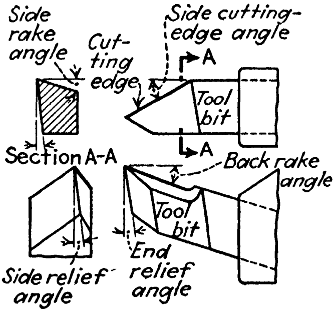


FIG. 9

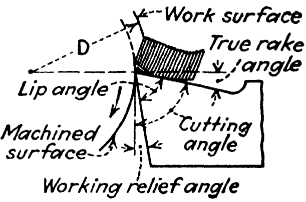


FIG. 11

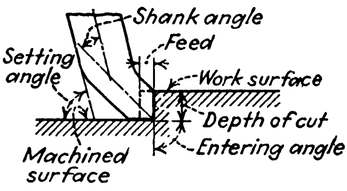


FIG. 12

FIGS. 7 to 12.—Angles of Single-Point Tools

Tool Bit.—A tool bit is a relatively small piece of cutting material, clamped in a tool shank or holder in such a way that it can readily be removed and replaced, Figs. 3, 7*b*, and 9.

Straight Tool.—A straight tool has the point on the forward end of a straight shank, Figs. 1 and 5.

Bent Tool.—A bent tool has the point bent to the left or right, Figs. 7*a* and 7*b*, to make its operation more convenient. These tools are called left-bent tools if the point is bent to the left when looking at the tool from the point end with the face upward and the shank pointing away, and *vice versa.*

Offset Tool.—An offset tool has the point at either side of, but parallel to, the shank. It is known as a right-offset tool if the point is offset to the right of the shank when looking at the tool from the point end with the face upward and the shank pointing away. Figure 8 illustrates a left-offset tool.

Right-Cut Tool.[1]—A right-cut single-point tool is one which, when viewed from the point end of the tool, with the face up, has the cutting edge on the right side, Figs. 1, 2, 4, 7*a*, 7*b*, and 10.

Left-Cut Tool.—A left-cut tool has the cutting edges on the left when looking at the point end with the face upward, Figs. 5, 6, 8, and 9.

End-Cut Tool.—An end-cut single-point tool is one having its principal cutting edge on the end.

TOOL ANGLES

Toolholder Angle.—The toolholder angle is that angle between the bottom of the bit slot and the base of the toolholder shank, Fig. 3.

Shank Angle.—The shank angle is the angle by which the point of a bent tool deviates from the straight portion of the shank, Figs. 7 and 12.

Back-Rake Angle.—The back-rake angle is the angle between the face of a tool and a line parallel to the base of the shank or holder measured in a plane parallel to the center line of the point and at right angles to the base. The angle is positive if the face slopes downward from the point toward the shank and is negative if the face slopes upward toward the shank, Fig. 9.

Side-Rake Angle.—The side-rake angle is the angle between the face of a tool and a line parallel to the base. It is measured in a plane at right angles to the base, and at right angles to the center line of the point, Fig. 9.

Relief Angle.—The relief angle is the angle between a plane perpendicular to the base of a tool or tool holder and the ground portion of the flank immediately adjacent to the cutting edge, Figs. 5 and 9.

Side-Relief Angle.—The side-relief angle is the angle between the portion of the flank immediately below the cutting edge and a line drawn through this cutting edge perpendicular to the base. It is measured in a plane at right angles to the center line of the point.

End-Relief Angle.—The end-relief angle is the angle between the portion of the end flank immediately below the cutting edge and a line drawn through that cutting edge perpendicular to the base, Figs. 5 and 9. It is measured in a plane parallel to the center line of the point.

Clearance Angle.—The clearance angle is the angle between a plane perpendicular to the base of a tool and that portion of the flank immediately adjacent to the base. The side clearance angle is measured in the plane of the side-rake angle. The end clearance angle is measured in the plane of the back-rake angle, Figs. 5 and 9.

The surfaces of the tool below the cutting edge are usually forged or rough ground before hardening so as to reduce the amount of grinding on the flank, Fig. 2. The ground flank sometimes extends to the heel, Fig. 1, in which case there is no clearance.

Side-Cutting-Edge Angle.—The side-cutting-edge angle is the angle between the straight side-cutting edge and the side of the tool shank, Fig. 10. In the case of a bent tool this angle is measured from the straight portion of the shank.

End-Cutting-Edge Angle.—The end-cutting-edge angle is the angle between the cutting edge on the end of the tool and a line at right angles to the side edge of the straight portion of the tool shank, Fig. 10.

As the setting angle is changed, the relation of the end-cutting edge to the work also is changed. See under "Working Angles."

Nose Angle.—The nose angle is the angle included between the side-cutting edge and end-cutting edge, Fig. 10.

WORKING ANGLES

Working Angles.—The working angles are those angles between tool and work, which depend not only on the shape of the tool, but also on its position with respect to the work, Fig. 11.

[1] **When such a tool is used in an engine lathe, the cutting edge is on the left side. It is fed into the work from right to left, as when cutting a right-hand screw thread.**

Setting Angle.—The setting angle is the angle made by the straight portion of the shank of a tool with the finished surface of the work, Fig. 12.

Entering Angle.—The entering angle is the angle which the side-cutting edge of a tool makes with the finished surface of the work, Figs. 7*a* and 12.

True-Rake Angle.—The true-rake angle (or "top-rake"), under actual cutting conditions is the actual slope of the tool face toward the base from the active cutting edge in the direction of chip flow. It is a combination of the back-rake and side-rake angles and varies with the setting of the tool and with the feed and depth of cut, Fig. 11.

Cutting Angle.—The cutting angle is the angle between the face of the tool and a tangent to the machined surface at the point of action. It equals 90 deg. minus the true-rake angle, Fig. 11.

Working-Relief Angle.—The working-relief angle is the angle between the ground flank of the tool and a line tangent to the machined surface passing through the active cutting edge, Fig. 11.

Working-End–Cutting-Edge Angle.—The working-end–cutting-edge angle is the angle between the straight-end cutting edge and a plane tangent to the machined surface at the point of cutting.

Lip Angle.—The lip angle is the included angle of the tool material between the face and the ground flank measured in a plane at right angles to the cutting edge. When measured in a plane perpendicular to the cutting edge at the end of the tool, it is called the end lip angle. When measured at the point of chip flow, it is called the true lip angle, Fig. 11.

GENERAL TERMS

Cutting Speed.—The cutting speed is the peripheral or surface speed of the work with respect to the tool. In turning, it is usually measured on the uncut or work surface of the work ahead of the tool. See Fig. 11.

EXAMPLE.—Cutting speed S in turning in feet per minute = $3.1416DN$
in which D = diameter of work in feet.
N = revolutions per minute of work.

Depth of Cut.—The depth of cut is the distance between the bottom of the cut and the uncut surface of the work, measured in a direction at right angles to the machined surface of the work, Figs. 7, 8, 11, and 12. This is the difference in height between the machined and work surfaces.

Feed.—The feed is the relative amount of motion of the tool into the work for each revolution, stroke, or unit of time, Fig. 12.

Machined Surface.—The machined surface is the surface left by the cutting tool, Figs. 7, 8, 11, and 12.

Work Surface.—The work surface refers to the surface to be machined, Figs. 7, 8, 11, and 12.

SYMBOLS

Recommended Symbols.—A recommended system of symbols for brevity in catalogs, purchase orders, etc., follows:

RC-S—Right-cut, single-point tool, with straight shank, Fig. 1.
LC-S—Left-cut, single-point tool, with straight shank, Fig. 5.
RC-RB—Right-cut, single-point tool, with right-bent shank, Fig. 7*b*.
RC-LB—Right-cut, single-point tool, with left-bent shank, Fig. 7*a*.
LC-RB—Left-cut, single-point tool, with right-bent shank.
LC-LB—Left-cut, single-point tool, with left-bent shank.
RC-RO—Right-cut, single-point tool, with right offset shank.
RC-LO—Right-cut, single-point tool, with left offset shank, Fig. 8.
LC-RO—Left-cut, single-point tool, with right offset shank.
LC-LO—Left-cut, single-point tool, with left offset shank.

Figure 13 shows the similarity between the best known cutting tools.

CONSTANTS FOR CUTTING TIME

An estimate of the time required for turning or boring work is often necessary. Multiplying the diameter in inches by 3.1416 and dividing by 12 gives the circumference in feet. Dividing the length of the cut in inches by the rate of feed per revolution gives the number of turns the piece must make. Multiplying the circumference by the number of revolutions gives the number of feet of tool travel. Dividing this by the cutting speed in feet per minute gives the actual cutting time in minutes.

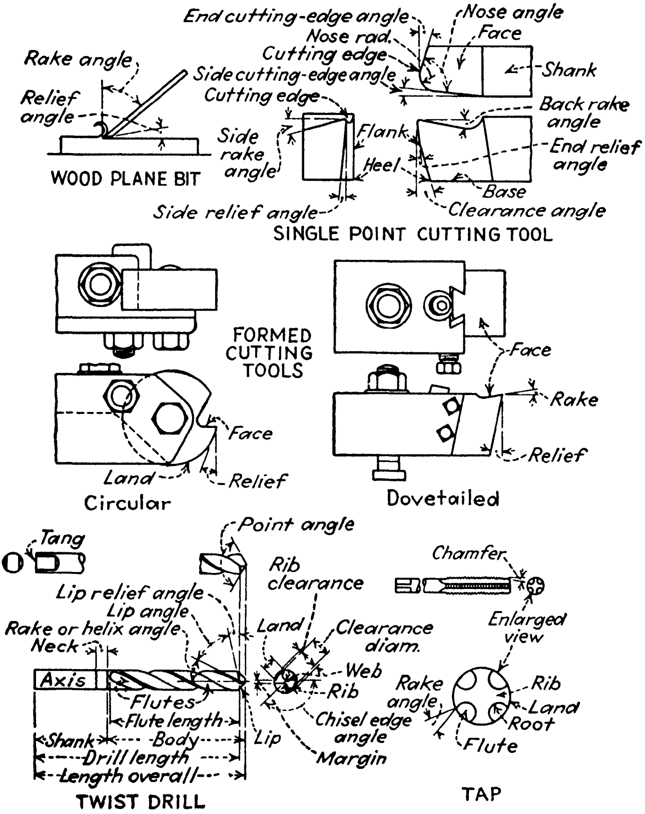


FIG. 13.—Names of Parts of Various Cutting Tools

The figuring can be resolved into the following formula:

$$\frac{\text{Diameter} \times 3.1416 \times \text{length in inches}}{12 \times \text{speed} \times \text{feed in inches}} = \text{time in minutes.}$$

The known factors in the case can be resolved into a constant which is directly dependent on the feed and speed; hence, a table covering a wide range of speeds and feeds is necessary for their proper use.

One part of the table gives constants for two cuts at $\frac{1}{64}$- and $\frac{1}{32}$-inch feed, up to $\frac{1}{8}$- and $\frac{1}{4}$-inch feed, at any speed from 20 to 65 feet per minute. The rest of the table gives constants for one cut at $\frac{1}{64}$-inch feed up to and including $\frac{1}{4}$-inch feed, also at any speed from 20 to 65 feet per minute.

A typical computation is as follows:

A piece 4 inches in diameter, 10 inches long, is turned with two cuts at $\frac{1}{16}$- and $\frac{1}{32}$-inch feed, each with a cutting speed of 20 feet per minute. Diameter × length in inches × constant = time in minutes. $4 \times 10 \times 0.6283 = 26$ minutes.

If, for the purpose of accuracy it is thought advisable, in connection with these two cuts, to run another cut over, the constant 0.6283 is added to a constant for the third feed used. If this feed is $\frac{1}{64}$ inch, then we have $0.6283 + 0.8378 = 1.4661$, the constant for three cuts, one of $\frac{1}{16}$-, one of $\frac{1}{32}$-, and one of $\frac{1}{64}$-inch feed.

TABLE 1.—CONSTANTS FOR CUTTING TIME IN MINUTES

Feed, in Inches	Cutting Speed, in Feet per Minute—Turning						
	20	25	30	35	45	55	65
Two cuts at:							
$\frac{1}{64}$ and $\frac{1}{32}$	1.257	1.005	0.8378	0.7181	0.5581	0.4572	0.386
$\frac{1}{32}$ and $\frac{1}{16}$	0.6283	0.5027	0.4189	0.3590	0.2793	0.2286	0.193
$\frac{1}{16}$ and $\frac{1}{8}$	0.3142	0.2513	0.2094	0.1795	0.1396	0.1143	0.097
$\frac{1}{8}$ and $\frac{1}{4}$	0.1571	0.1257	0.1047	0.0898	0.0698	0.0571	0.048
One cut at:							
$\frac{1}{64}$	0.8378	0.6702	0.5585	0.4787	0.3723	0.3046	0.257
$\frac{1}{32}$	0.4189	0.3351	0.2793	0.2394	0.1862	0.1523	0.128
$\frac{1}{16}$	0.2094	0.1676	0.1396	0.1197	0.0931	0.0761	0.064
$\frac{1}{8}$	0.1047	0.0838	0.0698	0.0598	0.0465	0.0381	0.032
$\frac{1}{4}$	0.0524	0.0419	0.0349	0.0299	0.0233	0.0191	0.016

The cutting speeds given were selected so that many others can be easily secured. Constants for any multiple of these can be found by dividing these constants by the multiplier used. Thus constants for 200 feet per minute are found by dividing those given in the 20 column by 10. For 195 feet cutting speed divide the constants in the 65 column by 3. For 210 feet divide constants in the 35 column by 6.

Table Has Wide Applications

There is hardly a combination of feeds and speeds that is not possible to secure by inspection from Table 1. By interpolation an added number can be secured.

The table can be adapted, on account of its wide range, to the known individual performance of any lathe or boring mill in the shop. No slide rule or any special operations are necessary to secure the desired results, merely a knowledge of multiplication.

For flange facing it is possible to use the table with the same ease as for boring and turning by figuring on the mean diameter.

Rotary Cutting Speeds

An easy method of calculating the cutting speed of a lathe tool or boring cutter is to divide the number of revolutions by 4 and multiply by the diameter in *inches*. This gives the approximate speed in *feet* per minute. This also applies to milling cutters.

Let D = diameter of work, cutter or boring bar.
N = revolutions per minute.
C = cutting speed in feet per minute.

$$C = D \times \frac{N}{4}. \qquad N = \frac{4 \times C}{D}. \qquad D = \frac{4 \times C}{N}.$$

Figuring Turning Speeds

A short-cut rule for quick mental calculation of turning speeds on a lathe or boring mill is: Multiply one-half the revolutions (per minute) by half the diameter (in inches). Add 1 for every 25 in the product. This result is the cutting speed in feet per minute.

EXAMPLE.—What is the cutting speed on a $1\frac{1}{2}$-inch diameter at 400 revolutions per minute?

SOLUTION.—$200 \times \frac{3}{4} = 150$; $150 \div 25 = 6$; $150 + 6 = 156$ feet per minute.

Frequently the following statement of the same formula is more convenient, as it avoids dividing the diameter, which sometimes makes a troublesome fraction: Multiply one-quarter the revolutions (per minute) by the diameter (in inches). Add 1 for every 25 in the product. The result is the cutting speed in feet per minute.

EXAMPLE.—What is the cutting speed on a $1\frac{1}{8}$-inch diameter at 440 rev. per minute?

SOLUTION.—$110 \times \frac{9}{8} = 124$; $124 \div 25 = 5$; $124 + 5 = 129$ feet per minute.

To see how closely this "rule of thumb" formula approximates the theoretical formula in accuracy, reduce both to similar terms in the latter example:

Practical formula: $\frac{1}{4} \times 440 \times \frac{9}{8} \times 1\frac{1}{25}$, or 440 (revolutions) × $\frac{9}{8}$ (diameter) × 0.260.

Theoretical formula: $3.1416 \times 440 \times \frac{9}{8} \times \frac{1}{12}$, or 440 (revolutions) × $\frac{9}{8}$ (diameter) × 0.262.

This comparison shows that when both formulas are reduced to similar terms, the discrepancy between the "constants" is only the difference between 0.260 and 0.262. This difference represents the amount of error, which is usually so much less than the error in roughly measuring the diameter or the revolutions per minute that it is negligible. Tables 2, 3 and 4 will save time.

Lathe Tool Tests

In testing steels for lathe and similar tools it has become customary to use standard material, speeds, feeds, and depth of cut. In some cases tools are run until they break down; in others, they are passed if they stand up for a specified time. A 20-point carbon steel is often selected and cuts $\frac{1}{4}$ inch deep with $\frac{1}{16}$- to $\frac{1}{8}$-inch feed at cutting speeds of from 60 to 90 feet per minute.

The United States Navy Department specifies that a $\frac{7}{8}$-inch lathe tool shall stand up for 20 minutes with a $\frac{3}{16}$-inch cut and $\frac{1}{16}$-inch feed at 60 feet per minute without regrinding; the material must be at least 80,000-pound tensile, and 50,000-pound elastic limit with a 25 per cent elongation in 2 inches. The steel is annealed before the test.

Accurate Tool Setting with Compound Rest

A compound rest fitted with a micrometer dial may be used to take very minute cuts by swiveling the rest to the proper point. Starting with the rest set to feed straight in and moving to the right, the in-feed will be the cosine of the angle. If the rest is moved 30 degrees from center, the in-feed, or cut taken, will be 0.86603 of the feed as shown on the dial. Or, for every 0.001 in. on the dial the actual in-feed is 0.000866 in. at 30 deg. With a 60 deg. setover the actual advance is one-half the amount shown on dial. The formulas are:

A = actual advance of tool in radial direction.
B = amount removed on diameter of work $= 2A$.
C = number of degrees of setover of compound rest, from center.
D = advance as read on dial in 0.001 of inch.
$A = D \times \cos C$. $B = 2A$.

$$\cos \text{ of } C = \frac{A}{D} \text{ or } C = \text{angle whose cos is } \frac{A}{D}.$$

Cutting Lubricants

Cast iron is usually worked dry, but when hard cast-iron gears are to be cut, as with three cutters, the first cut through will work better with strong soda water. It makes an objectionable mess, but the work will be done faster and the cutters keep sharper longer than with the dry process of cutting.

Brass and babbitt are usually cut dry, but to hand-ream brass and babbitt is sometimes difficult if the reamer is a little dull. Kerosene and turpentine are used with good results. Cast iron can be hand-reamed easily with tallow and graphite, mixed, and the hole will be kept just the size of the reamer. Copper can be worked well with lard oil and turpentine mixed.

In boring babbitt bushings and rod boxes in a lathe or boring mill, it is very difficult to work the material dry as the chips have a great tendency to roll around the tool and into a hard ball, tearing the metal and making a rough ragged hole. In this case kerosene and lard oil mixed will work well.

Turpentine is good in some cases where fitting is done, such as scraping lay-out plates, or face plates. Oil will form a coating so that marks cannot be seen plainly, but turpentine will prove beneficial on this kind of work if used freely. The marks can be seen plainly, and the work is a great deal easier to scrape than with an oil surface, as the oil glazes over the surface and makes it hard to start the scraper cutting.

TABLE 2.—CUTTING SPEED CONVERSION TABLE

Surface Feet to Revolutions per Minute

Feet per Minute

Higher cutting speeds are easily found by multiplication. For 150 feet, use the 50 column and multiply by 3, or use the 75 column and multiply by 2. For 350 feet, use 70 column and multiply by 5.

Diameter, Inches	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85
	Revolutions per Minute														
1/16	917	1,223	1,528	1,834	2,140	2,445	2,751	3,057	3,363	3,668	3,974	4,280	4,586	4,891	5,197
1/8	459	611	764	917	1,070	1,222	1,375	1,528	1,681	1,834	1,986	2,139	2,292	2,445	2,598
3/16	306	408	509	611	713	815	917	1,019	1,121	1,222	1,325	1,426	1,529	1,630	1,732
1/4	229	306	382	458	535	611	688	764	851	917	994	1,070	1,147	1,122	1,300
5/16	183	245	306	367	428	489	550	611	672	733	794	856	917	978	1,039
3/8	153	204	255	306	357	408	458	509	560	611	662	713	764	815	865
7/16	131	175	218	262	306	349	393	437	481	524	568	611	656	699	743
1/2	115	153	191	229	268	306	344	382	420	459	497	535	573	611	649
9/16	102	136	170	204	238	272	306	340	373	407	441	475	509	543	577
5/8	91.8	123	153	184	214	245	276	306	337	367	398	428	459	489	520
11/16	83.3	111	138	167	194	222	249	273	300	333	360	389	416	444	472
3/4	76.3	102	127	153	178	203	229	254	279	306	330	357	381	408	432
13/16	71.1	94.8	119	142	166	190	213	237	261	284	308	332	356	379	403
7/8	65.5	87.3	109	131	153	175	196	219	241	262	285	306	329	349	372
15/16	61.0	81.4	101	122	142	163	183	204	224	244	265	285	305	326	346
1	57.3	76.4	95.5	115	134	153	172	191	210	229	258	267	287	306	325
1 1/16	53.9	71.8	89.9	108	126	144	162	180	197	215	233	251	269	287	305
1 1/8	51.0	68.0	85.0	102	119	136	153	170	187	204	221	238	255	272	289
1 3/16	48.3	64.4	80.5	96.6	113	129	145	161	177	193	209	225	242	258	274
1 1/4	45.8	61.2	76.3	91.8	107	123	137	153	168	183	199	214	230	245	260
1 5/16	43.6	58.2	72.8	87.3	102	116	131	146	160	175	189	204	218	233	247
1 3/8	41.7	55.6	69.5	83.3	97.2	111	125	139	153	167	180	195	208	222	236
1 7/16	39.8	53.0	66.3	79.5	92.8	106	119	133	146	159	172	186	199	212	225
1 1/2	38.2	50.8	63.7	76.3	89.2	102	115	127	140	153	165	178	191	204	216
1 9/16	36.6	48.8	61.0	73.2	85.4	97.6	110	122	134	146	159	171	183	195	207
1 5/8	35.0	47.0	58.8	70.5	82.2	93.9	106	117	129	141	152	165	176	188	199
1 11/16	33.9	45.2	56.5	67.8	79.1	90.4	102	113	124	136	147	158	170	181	192
1 3/4	32.7	43.6	54.5	65.5	76.4	87.3	98.2	109	120	131	142	153	164	175	185

1 13/16	31.7	42.2	52.8	63.3	73.9	84.4	95.0	106	119	127	137	148	158	169	179
1 7/8	30.6	40.7	50.9	61.1	71.3	81.5	91.9	102	112	122	133	143	153	163	173
1 15/16	29.6	39.4	49.3	59.1	69.0	78.8	88.7	98.5	108	118	128	138	148	158	167
2	28.7	38.2	47.8	57.3	66.9	76.4	86.0	95.5	105	115	124	134	143	153	162
2 1/8	27.0	36.0	45.0	54.0	63.0	72.0	81.0	90.0	99.0	108	117	126	135	144	153
2 1/4	25.4	34.0	42.4	51.0	59.4	68.0	76.2	85.5	93.5	102	111	119	128	136	145
2 3/8	24.2	32.2	40.3	48.3	56.4	64.4	72.5	80.5	88.6	96.6	105	113	121	129	137
2 1/2	22.9	30.6	38.2	45.8	53.5	61.2	68.8	76.3	84.2	91.7	99.5	107	114	122	130
2 5/8	21.8	29.0	36.3	43.5	50.8	58.0	65.3	72.5	79.8	87.0	94.3	102	109	116	123
2 3/4	20.8	27.8	34.7	41.7	48.6	55.6	62.5	69.5	76.5	83.4	90.4	97.2	104	111	118
2 7/8	19.8	26.4	33.0	39.6	46.2	52.8	59.4	66.0	72.6	79.2	85.8	92.4	99.0	106	112
3	19.1	25.5	31.8	38.2	44.6	51.0	57.3	63.7	69.9	76.4	82.6	89.1	95.3	102	108
3 1/8	18.3	24.4	30.5	36.6	42.7	48.8	54.9	61.0	67.1	73.2	79.3	85.4	91.5	97.6	104
3 1/4	17.6	23.4	29.3	35.1	41.0	46.8	52.7	58.5	64.4	70.2	76.1	81.9	87.8	93.6	99.5
3 3/8	17.0	22.6	28.3	33.9	39.6	45.2	50.9	56.5	62.2	67.8	73.5	79.1	84.8	90.4	96.1
3 1/2	16.4	21.8	27.3	32.7	38.2	43.6	49.1	54.5	60.0	65.5	70.8	76.4	81.8	87.4	92.7
3 5/8	15.8	21.0	26.3	31.5	36.8	42.0	47.3	52.5	57.8	63.0	68.3	73.5	78.8	84.0	89.3
3 3/4	15.3	20.4	25.5	30.6	35.7	40.8	45.9	51.0	56.1	61.2	66.3	71.4	76.5	81.6	86.7
3 7/8	14.8	19.7	24.6	29.6	34.5	39.4	44.3	49.3	54.2	59.1	64.0	69.0	73.8	78.8	83.7
4	14.3	19.1	23.9	28.7	33.4	38.2	43.0	47.8	52.6	57.3	62.1	66.9	71.7	76.4	81.3
4 1/4	13.5	18.0	22.5	26.9	31.4	35.9	40.4	44.9	49.4	53.9	58.4	62.9	67.4	71.8	76.3
4 1/2	12.7	16.9	21.2	25.4	29.6	34.0	38.2	42.4	46.6	51.0	55.1	59.4	63.6	67.9	72.1
4 3/4	12.1	16.1	20.1	24.1	28.1	32.2	36.2	40.2	44.2	48.2	52.3	56.3	60.3	64.3	68.3
5	11.5	15.3	19.1	22.9	26.7	30.6	34.4	38.2	42.0	45.9	49.7	53.5	57.3	61.1	64.9
5 1/4	10.9	14.5	18.2	21.8	25.4	29.1	32.7	36.4	40.0	43.6	47.3	50.9	54.5	58.2	61.8
5 1/2	10.4	13.9	17.4	20.8	24.3	27.8	31.3	34.7	38.2	41.7	45.1	48.6	52.0	55.6	59.0
5 3/4	10.0	13.3	16.6	19.9	23.2	26.6	29.9	33.2	36.5	39.8	43.2	46.5	49.8	53.1	56.4
6	9.6	12.7	15.9	19.1	22.3	25.5	28.7	31.8	35.0	38.2	41.3	44.6	47.7	51.0	54.0
6 1/4	9.2	12.2	15.3	18.3	21.4	24.4	27.5	30.6	33.6	36.7	39.7	42.8	45.8	48.9	51.9
6 1/2	8.8	11.7	14.7	17.6	20.5	23.5	26.4	29.4	32.3	35.2	38.2	41.1	44.0	47.0	49.9
6 3/4	8.5	11.3	14.2	17.0	19.8	22.6	25.5	28.3	31.1	34.0	36.8	39.6	42.5	45.3	48.1
7	8.1	10.9	13.6	16.4	19.1	21.8	24.6	27.3	30.0	32.7	35.5	38.2	41.0	43.7	46.0
7 1/4	7.9	10.5	13.2	15.8	18.4	21.1	23.7	26.4	29.0	31.6	34.3	36.9	39.5	42.2	44.8
7 1/2	7.6	10.2	12.7	15.3	17.8	20.4	22.9	25.4	28.0	30.5	33.2	35.6	38.2	40.7	43.3
7 3/4	7.4	9.8	12.3	14.8	17.2	19.7	22.1	24.6	27.1	29.5	32.0	34.4	36.9	39.4	42.8
8	7.2	9.6	11.9	14.3	16.7	19.1	21.1	23.9	26.3	28.7	31.0	33.4	35.9	38.2	40.6

TABLE 3.—TIME REQUIRED FOR TOOL TO TRAVEL 1 INCH When Feed Is 1/100 Inch per Revolution

Diameter, Inches	Surface Speed per Minute															
	20		25		30		35		40		45		50		60	
	M.	S.	M.	S.	M.	S.	M.	S.	M.	S.	M.	S.	M.	S.	M.	S.
¼	0	20	0	16	0	13	0	11	0	10	0	9	0	8	0	7
5/16	0	25	0	20	0	17	0	14	0	13	0	11	0	10	0	9
⅜	0	29	0	23	0	19	0	17	0	15	0	13	0	12	0	10
7/16	0	34	0	27	0	23	0	19	0	17	0	15	0	14	0	12
½	0	39	0	31	0	26	0	22	0	20	0	17	0	16	0	13
9/16	0	44	0	35	0	29	0	25	0	22	0	19	0	18	0	15
⅝	0	49	0	39	0	32	0	28	0	25	0	22	0	20	0	16
11/16	0	54	0	43	0	36	0	31	0	27	0	24	0	22	0	18
¾	0	59	0	47	0	39	0	34	0	30	0	26	0	24	0	20
13/16	1	4	0	51	0	42	0	36	0	32	0	28	0	26	0	21
⅞	1	9	0	55	0	46	0	39	0	35	0	30	0	28	0	23
15/16	1	14	0	59	0	49	0	42	0	37	0	33	0	30	0	25
1	1	19	1	3	0	52	0	45	0	40	0	35	0	32	0	26
1⅛	1	28	1	10	0	58	0	50	0	44	0	39	0	35	0	29
1¼	1	38	1	18	1	5	0	56	0	49	0	43	0	39	0	33
1⅜	1	48	1	26	1	11	1	2	0	54	0	48	0	43	0	36
1½	1	58	1	34	1	18	1	7	0	59	0	52	0	47	0	39
1⅝	2	8	1	42	1	24	1	13	1	4	0	56	0	51	0	42
1¾	2	18	1	50	1	31	1	19	1	9	1	1	0	55	0	46
1⅞	2	27	1	58	1	37	1	24	1	14	1	5	0	59	0	49
2	2	37	2	6	1	44	1	29	1	19	1	9	1	3	0	52
2⅛	2	46	2	13	1	50	1	34	1	23	1	13	1	6	0	55
2¼	2	56	2	21	1	56	1	40	1	28	1	17	1	11	0	58
2⅜	3	6	2	29	2	3	1	46	1	33	1	22	1	15	1	2
2½	3	16	2	37	2	9	1	52	1	38	1	26	1	19	1	5
2¾	3	37	2	54	2	23	2	4	1	49	1	35	1	27	1	12
3	3	56	3	9	2	36	2	15	1	58	1	44	1	34	1	18
3¼	4	16	3	25	2	49	2	26	2	8	1	53	1	42	1	25
3½	4	35	3	40	3	2	2	37	2	18	2	1	1	50	1	31
3¾	4	56	3	57	3	15	2	49	2	28	2	10	1	58	1	38
4	5	14	4	11	3	27	2	59	2	37	2	18	2	6	1	44
4¼	5	33	4	26	3	40	3	10	2	47	2	27	2	13	1	50
4½	5	52	4	42	3	52	3	21	2	56	2	35	2	21	1	56
4¾	6	12	4	58	4	6	3	32	3	6	2	44	2	29	2	3
5	6	32	5	14	4	19	3	43	3	16	2	52	2	37	2	10
5½	7	15	5	48	4	47	4	8	3	37	3	11	2	54	2	24
6	7	52	6	18	5	12	4	29	3	56	3	28	3	9	2	36
6½	8	33	6	50	5	39	4	52	4	17	3	46	3	25	2	50
7	9	10	7	20	6	3	5	14	4	35	4	2	3	40	3	2
7½	9	54	7	55	6	32	5	39	4	57	4	21	3	58	3	16
8	10	28	8	22	6	54	5	58	5	14	4	36	4	11	3	27
8½	11	7	8	54	7	20	6	20	5	34	4	53	4	27	3	40
9	11	46	9	25	7	46	6	42	5	53	5	11	4	42	3	53
9½	12	25	9	56	8	12	7	5	6	12	5	28	4	58	4	6
10	13	9	10	31	8	40	7	30	6	34	5	47	5	16	4	20
10½	13	40	10	56	9	2	7	47	6	50	6	1	5	28	4	31
11	14	30	11	36	9	34	8	16	7	15	6	23	5	48	4	47
11½	15	2	12	2	9	55	8	34	7	31	6	37	6	1	4	58
12	15	44	12	35	10	23	8	58	7	52	6	55	6	18	5	14
12½	16	24	13	7	10	49	9	21	8	12	7	13	6	34	5	25
13	17	4	13	39	11	16	9	44	8	32	7	31	6	50	5	38
13½	17	32	14	2	11	34	10	0	8	46	7	43	7	1	5	47
14	18	20	14	40	12	6	10	27	9	10	8	4	7	20	6	3
14½	18	52	15	6	12	28	10	46	9	26	8	19	7	33	6	14
15	19	38	15	41	12	57	11	10	9	49	8	38	7	50	6	29
15½	20	24	16	19	13	28	11	38	10	12	9	0	8	10	6	44
16	20	58	16	46	13	50	11	57	10	29	9	13	8	23	6	55

TABLE 4.—LATHE AND BORING-MILL TIME

Diam. of Work	Cutting Speed, Feet per Minute							
	25				30			
	Feeds, Inches per Rev.				Feeds, Inches per Rev.			
	1/32	1/8	1/4	1/2	1/32	1/8	1/4	1/2
2	8.042	2.011	1.005	0.503	6.702	1.675	0.838	0.419
2½	10.053	2.513	1.257	0.628	8.378	2.094	1.047	0.524
3	12.064	3.016	1.508	0.754	10.053	2.513	1.257	0.628
3½	14.074	3.519	1.759	0.880	11.729	2.932	1.466	0.733
4	16.085	4.021	2.011	1.005	13.404	3.351	1.676	0.838
4½	18.096	4.524	2.262	1.131	15.080	3.770	1.885	0.942
5	20.106	5.027	2.513	1.257	16.755	4.189	2.094	1.047
5½	22.117	5.529	2.765	1.382	18.431	4.608	2.304	1.152
6	24.127	6.032	3.016	1.508	20.106	5.027	2.513	1.257
6½	26.138	6.535	3.267	1.634	21.782	5.445	2.723	1.361
7	28.149	7.037	3.519	1.759	23.457	5.864	2.932	1.466
7½	30.159	7.540	3.770	1.885	25.133	6.283	3.142	1.571
8	32.170	8.042	4.021	2.011	26.808	6.702	3.351	1.676
8½	34.181	8.545	4.273	2.136	28.484	7.121	3.560	1.780
9	36.191	9.048	4.524	2.262	30.159	7.540	3.770	1.885
9½	38.202	9.550	4.775	2.388	31.835	7.959	3.979	1.990
10	40.212	10.053	5.027	2.513	33.510	8.378	4.189	2.094
10½	42.223	10.556	5.278	2.639	35.186	8.796	4.398	2.199
11	44.234	11.058	5.529	2.765	36.861	9.215	4.608	2.304
11½	46.244	11.561	5.781	2.890	38.537	9.634	4.817	2.499
12	48.255	12.064	6.032	3.016	40.212	10.053	5.027	2.513
12½	50.266	12.566	6.283	3.142	41.888	10.472	5.236	2.618
13	52.276	13.069	6.535	3.267	43.564	10.891	5.445	2.723
13½	54.287	13.572	6.786	3.393	45.239	11.310	5.655	2.827
14	56.297	14.074	7.037	3.519	46.915	11.729	5.864	2.932
14½	58.308	14.577	7.289	3.644	48.590	12.148	6.074	3.037
15	60.319	15.080	7.540	3.770	50.266	12.566	6.283	3.142
15½	62.329	15.582	7.791	3.896	51.941	12.985	6.493	3.246
16	64.340	16.085	8.042	4.021	53.617	13.404	6.702	3.351
16½	66.351	16.588	8.294	4.147	55.292	13.823	6.912	3.456
17	68.361	17.090	8.545	4.273	56.968	14.242	7.121	3.560
17½	70.372	17.593	8.796	4.398	58.643	14.661	7.330	3.665
18	72.382	18.096	9.048	4.524	60.319	15.080	7.540	3.770
18½	74.393	18.598	9.299	4.650	61.994	15.499	7.749	3.875
19	76.404	19.101	9.550	4.775	63.670	15.917	7.959	3.979
19½	78.414	19.604	9.802	4.901	65.345	16.336	8.168	4.084
20	80.425	20.106	10.053	5.027	67.021	16.755	8.378	4.189
21	84.446	21.112	10.556	5.278	70.372	17.593	8.796	4.398
22	88.467	22.117	11.058	5.529	73.723	18.431	9.215	4.608
23	92.489	23.122	11.561	5.781	77.074	19.268	9.634	4.817
24	96.510	24.127	12.064	6.032	80.425	20.106	10.053	5.027
25	100.53	25.133	12.566	6.283	83.776	20.944	10.472	5.236
26	104.55	26.138	13.069	6.535	87.127	21.782	10.891	5.445
27	108.57	27.143	13.572	6.786	90.478	22.620	11.310	5.655
28	112.59	28.149	14.074	7.037	93.829	23.457	11.729	5.864
29	116.62	29.154	14.577	7.289	97.180	24.295	12.148	6.074
30	120.64	30.159	15.080	7.540	100.53	25.133	12.566	6.283

TABLE 4.—LATHE AND BORING-MILL TIME—*Continued*

Diam. of Work	Cutting Speed, Feet per Minute							
	35				40			
	Feeds, Inches per Rev.				Feeds, Inches per Rev.			
	1/32	1/8	1/4	1/2	1/32	1/8	1/4	1/2
2	5.745	1.436	0.718	0.359	5.027	1.257	0.628	0.314
2½	7.181	1.795	0.898	0.449	6.283	1.571	0.785	0.393
3	8.617	2.154	1.077	0.539	7.540	1.885	0.942	0.471
3½	10.053	2.513	1.257	0.624	8.796	2.199	1.100	0.550
4	11.489	2.872	1.436	0.718	10.053	2.513	1.257	0.628
4½	12.925	3.231	1.616	0.808	11.310	2.827	1.414	0.707
5	14.362	3.590	1.795	0.898	12.566	3.142	1.571	0.785
5½	15.798	3.949	1.975	0.987	13.823	3.456	1.728	0.864
6	17.234	4.308	2.154	1.077	15.080	3.770	1.885	0.942
6½	18.670	4.668	2.334	1.167	16.336	4.084	2.042	1.021
7	20.106	5.027	2.513	1.257	17.593	4.398	2.199	1.100
7½	21.542	5.386	2.693	1.346	18.850	4.712	2.356	1.178
8	22.979	5.745	2.872	1.436	20.106	5.027	2.513	1.257
8½	24.415	6.104	3.052	1.526	21.363	5.341	2.670	1.335
9	25.851	6.463	3.231	1.616	22.620	5.655	2.827	1.414
9½	27.287	6.822	3.411	1.705	23.876	5.969	2.985	1.492
10	28.723	7.181	3.590	1.795	25.133	6.283	3.142	1.571
10½	30.159	7.540	3.770	1.885	26.389	6.597	3.299	1.649
11	31.596	7.899	3.949	1.975	27.646	6.912	3.456	1.728
11½	33.032	8.258	4.129	2.064	28.903	7.226	3.613	1.806
12	34.468	8.617	4.308	2.154	30.159	7.540	3.770	1.885
12½	35.904	8.976	4.488	2.244	31.416	7.854	3.927	1.964
13	37.340	9.335	4.668	2.334	32.673	8.168	4.084	2.042
13½	38.776	9.694	4.847	2.424	33.929	8.482	4.241	2.121
14	40.212	10.053	5.027	2.513	35.186	8.796	4.398	2.199
14½	41.649	10.412	5.206	2.603	36.443	9.111	4.555	2.278
15	43.085	10.771	5.386	2.693	37.699	9.425	4.712	2.356
15½	44.521	11.130	5.565	2.783	38.956	9.739	4.869	2.435
16	45.957	11.489	5.745	2.872	40.212	10.053	5.027	2.513
16½	47.393	11.848	5.924	2.962	41.469	10.367	5.184	2.592
17	48.829	12.207	6.104	3.052	42.726	10.681	5.341	2.670
17½	50.266	12.566	6.283	3.142	43.982	10.996	5.498	2.749
18	51.702	12.925	6.463	3.231	45.239	11.310	5.655	2.828
18½	53.138	13.284	6.642	3.321	46.496	11.624	5.812	2.906
19	54.574	13.644	6.822	3.411	47.752	11.938	5.969	2.985
19½	56.010	14.003	7.001	3.501	49.009	12.252	6.126	3.063
20	57.446	14.362	7.181	3.590	50.266	12.566	6.283	3.142
21	60.319	15.080	7.540	3.770	52.779	13.195	6.597	3.299
22	63.191	15.798	7.899	3.949	55.292	13.823	6.912	3.456
23	66.063	16.516	8.258	4.129	57.805	14.451	7.226	3.613
24	68.936	17.234	8.617	4.308	60.319	15.080	7.540	3.770
25	71.808	17.952	8.976	4.488	62.832	15.708	7.854	3.927
26	74.680	18.670	9.335	4.668	65.345	16.336	8.168	4.084
27	77.553	19.388	9.694	4.847	67.859	16.965	8.482	4.241
28	80.425	20.106	10.053	5.027	70.372	17.593	8.796	4.398
29	83.297	20.824	10.412	5.206	72.885	18.221	9.111	4.555
30	86.170	21.542	10.771	5.386	75.398	18.850	9.425	4.712

For speeds of 50, 60, 70, and 80 feet per minute, divide these time values by 2. For speeds of 75, 90, 105, and 120 feet per minute, divide by 3. Other speed values can be found in the same way.

LUBRICANTS FOR THREADING

Aluminum.—For aluminum, kerosene with enough cutting oil to give it a body. For many purposes a soluble cutting oil is satisfactory.

Basic Steel.—The same good mineral lard oil that was used for threading Bessemer steel has worked well for basic steel.

Bessemer Steel.—In cutting the regular grades of Bessemer steel a good mineral lard oil has been used with results wholly satisfying. Sometimes the mineral lard oil has been mixed with a certain percentage of ordinary kerosene oil, ranging from 25 to 50 per cent, according to the nature of the work.

Copper.—Frequently cut dry, but good cooling compound preferred.

Cast Iron.—Mineral lard oil.

Hard rubber and fiber are threaded without any lubrication.

Monel Metal.—In threading monel metal a compound of white lead and oil has been used successfully. Others claim better results from red lead and oil. If the lead and oil are mixed to the consistency of thin glue and applied to the work, there would probably be no difficulty in cutting monel metal successfully, so far as the lubricant is concerned.

Phosphor Bronze Studs.—Mineral lard oil straight or diluted with 25 per cent kerosene oil.

Soft Drawn Steel and Soft Steel Forgings.—Prime lard oil, or the compound for general threading, given here:

COMPOUND FOR GENERAL THREADING

A British lubricant for thread cutting is made of 33 parts tallow, 23 parts white lead, 3 parts graphite, 41 parts fatty oil.

LUBRICANTS FOR MACHINE THREADING

(Landis Machine Company)

Tool steel Vanadium steel Nickel steel Open-hearth steel Machine steel Bessemer steel Screw stock Merchant pipe Seamless tubing	A heavy sulphur-base oil will give the best results, due to its cooling efficiency. On the freer-cutting steels mineral oil or paraffin oil can be used, when sulphur-base oil is objectionable
Cast iron Malleable iron	Mineral oil or compound, of a mixture 40 gallons water, 10 gallons mineral lard oil, and 2½ pounds of soda ash
Phosphor bronze Copper Drawn brass Aluminum Lead	Mineral lard oil diluted with 30 to 40 per cent kerosene
Cast brass Hard rubber Fiber Bakelite	Dry

TABLE 5.—CUTTING FLUIDS APPLICATION CHART[1]

Type of Machine Tool	Aluminum	Copper	Cast Iron	Malleable Iron	Cold-Rolled Steel	Axle Steel	Tool Steel Annealed	Heat-Treated Steel	Stainless Steel	Monel Metal
Lathes	1-2-3-4 5-6 F	3-4-5 D	3-4-5 G	1-6-K 3-4-5-G	1-6-K 3-4-5-G	1-6-K 3-4-5-G	1-6-K 3-4-5-I	1-6-K 3-4-5-I	1-6-K 3-4-5-I	1-6-K 3-4-5-I
Semi-automatic lathes	1-2-3 4-5-6 F	1-2-6-E		1-2-6-K	1-6-K	1-6-K	1-6-K	1-6-K	1-6-K	1-6-K
Turret lathes	1-2-3 4-5-6 F	1-2-3 4-5-6 D	3-4-5	1-2-6-K 3-4-5-G	1-6-K 3-4-5-G	1-6 3-4-5-G	1-6-G 3-4-5-I	1-6-G 3-4-5-I	1-6-G 3-4-I 5-G	1-6-G 3-4-I 5-G
Hand screw machines	1-2-3 4-5-6 F	1-2-3 4-5-6 D	3-4-5 G	1-2-6-K 3-4-5-G	1-6-K 3-4-5-E	1-6-K 3-4-5-D	1-6-K 3-4-5-I	1-6-K 3-4-5-I	1-6-K 3-4-5-I	1-6-K 3-4-5-I
Automatic screw machines, single spindle		1-2-3 4-5-6 D			1-2-3 5-6 E	1-2-3 5-6 D	1-2-3 5-6 D			
Automatic screw machines, multiple spindle		1-2-3 4-5-6 D			1-2-3 4-6 E	1-2-3 5-6 D				
Semi-automatic chucking machines	1-2-3 4-5-6 F	1-2-3 4-5-6 D	3-4-5 G	1-2-6-K 3-4-5-G	1-2-6-K 3-4-5-I	1-2-6-K 3-4-5-I	1-2-6-K 3-4-5-I	1-2-6-K 3-4-5-I	1-2-6-K 3-4-5-I	1-2-6-K 3-4-5-I
Pipe cutters	3-6-F	3-6-F	3-6-G	3-6-G	3-6-G	3-6-D				
Bolt cutters	3-F	3-D		3-G	3-G	3-D	3-D	3-D	3-D	3-D
Gear and thread hobbers	1-2-3 F	3-D		1-2-3-6 G	1-2-3-6 G	1-2-3-6 D	1-2-3-6 D	1-2-3-6 D	1-2-3-6 D	1-2-3-6 D
Gear shapers	6-F	1-2-6-E		1-6-K	1-2-6-E	1-2-6-E	1-2-6-E	1-2-6-E	1-2-6-E	1-2-6-E

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[1] J. G. Roney and G. L. Sumner of the Westinghouse Electric & Mfg. Co.

TABLE 5.—CUTTING FLUIDS APPLICATION CHART[1]—*Continued*

Type of Machine Tool	Aluminum	Copper	Cast Iron	Malleable Iron	Cold-Rolled Steel	Axle Steel	Tool Steel Annealed	Heat-Treated Steel	Stainless Steel	Monel Metal
Thread millers	3-F	3-D		3-G	3-E	3-D	3-D	3-D	3-D	3-D
Vertical boring mills	1-2-3 4-5-6 F	1-2-6-K 3-4-5 D	4-5-G	1-2-6-K 4-5-G	1-2-6-K 4-5-G	1-2-6-K 4-5-G	1-2-6-K 4-5-I	1-2-6-K 4-5-I	1-2-6-K 4-5-I	1-2-6-K 4-5-I
Horizontal boring mills	1-2-4 5-6 F	1-2-6-K 4-5-D	4-5-G	1-2-6-K 4-5-G	1-2-6-K 4-5-G	1-2-6-K 4-5-I	1-2-6-K 4-5-I	1-2-6-K 4-5-I	1-2-6-K 4-5-I	1-2-6-K 4-5-I
Planers and shapers	6-F	1-2-6-K								
Vertical milling machines	6-F	1-2-6-K		6-K	6-K	6-K	6-K	6-K	6-K	6-K
Horizontal milling machines	6-F	1-2-6-K		6-K	6-K	6-K	6-K	6-K	6-K	6-K
Slotters and key seaters	6-F	1-2-6-K				6-E	6-E	6-E	6-E	6-E
Drill presses	1-4-5-F	6-K 4-5-D	4-5-G	1-6-K 4-5-G	6-K 4-5-G	6-K 4-5-G	6-K 4-5-G	6-K 4-5-G	6-K 4-5-G	6-K 4-5-G
Tappers	4-F	4-D	4-G	4-G	4-G	4-G	4-G	4-G	4-G	4-G
Internal grinding machine	6-J	6-C	6-C	6-C	6-C	6-C	6-C	6-C	6-C	6-C
Cylinder and horizontal grinding machines	6-J	6-C	6-C	6-C	6-C	6-C	6-C	6-C	6-C	6-C
	6-J	6-B	6-B	6-B	6-B	6-B	6-B	6-B	6-B	6-B
Lapping machines	6-J	6-H	6-H	6-H	6-H	6-H	6-H	6-H	6-H	6-H
Honing machines	6-J	6-J	6-J	6-J	6-J	6-J	6-J	6-J	6-J	6-J
Broaching machines	6-F	6-D		6-D	6-D	6-D	6-D	6-D	6-D	6-D
Power saws	6-K	6-K		6-K	6-K	6-K	6-K	6-K	6-K	6-K
Draw presses										
Punch presses	6-F	6-D								

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[1] J. G. Roney and G. L. Sumner of the Westinghouse Electric & Mfg. Co.

TABLE 5.—CUTTING FLUIDS APPLICATION CHART.[1]—*Continued*

Type of Machine Tool	Soft Brass	Cast Brass	Bronze Rod	Cast Bronze	Cast Steel	Wrought Iron	Sheet Iron	Fiber	Hard Rubber	Micarta
Lathes	1-2-3 4-5-6 K	1-6-K 3-4-G 5-K	1-6-K 3-4-5-D	1-6-K 3-4-5-I	1-6-K 3-4-5-I	1-6-K 3-4-5-I and G		3-4 M		6 L
Semi-automatic lathes	1-6-K	1-6-K	1-6-K	1-6-K	1-6-K	1-6-K				
Turret lathes	1-6-K	1-6-K 3-4-5-G	1-6-K 3-4-5-G	1-6-K 3-4-5-D	1-6-K 3-4-5-I	1-6-K 3-4-5-I 3-4-5-G		3-4 M		6 L
Hand screw machines	1-6 2-3-4-5 K	1-6-K 3-4-5-G	1-6-K 3-4-5 D	1-6-K 3-4-5 D	1-6-K 3-4-5-I	1-6-K 3-4-5-I 3-4-5-G		3-4 M		6 L
Automatic screw machines, single spindle	1-2-3 4-5-6 E		1-2-3 4-5-6 D							
Automatic screw machines, multiple spindle	1-2-3 4-5-6 E		1-2-3 4-5-6 D							
Semi-automatic chucking machines	1-2-3 4-5-6 K	1-2-6-K 3-4-5-I	1-2-6-K 3-4-5-D	1-2-6-K 3-4-5-D	1-2-6-K 3-4-5-I	1-2-6-K 3-4-5-I 3-4-5-G		3-4 M		
Pipe cutters	3-6-G	3-6-G				3-6-G				
Bolt cutters	3-G	3-G	3-G	3-G		3-G	3-G			
Gear and thread hobbers	1-2-3-6 E	1-2-3-6 E	1-2-3-6 D	1-2-3-6 D	1-2-3-6 D	1-2-3-6 G				
Gear shapers	1-2-6-E	1-2-6-E	1-2-6-D	1-2-6-D	1-2-6-E	1-2-6-E				
Thread millers	3-E	3-E	3-D	3-D	3-D	3-D				
Vertical boring mills	1-2-4 5-6 K	1-2-6-K 4-5-G	1-2-6-K 4-5-D	1-2-6-K 4-5-D	1-2-6-K 4-5-I	1-2-6-K 4-5-I 4-5-G		4 M		

Horizontal boring mills.	1-2-4 5-6 K	1-2-6-K 4-5-G	1-2-6-K 4-5-D	1-2-6-K 4-5-D	1-2-6-K 4-5-I	1-2-6-K 4-5-I 4-5-G		4 M		
Planers and shapers										
Vertical milling machines	6-K	6-K	6-K	6-K	6-K	6-K	6-K			
Horizontal milling machines	6-K	6-K	6-K	6-K	6-K	6-K	6-K			
Slotters and key seaters	6-K	6-K	6-E	6-E	6-E	6-E	6-E			
Drill presses	4-5-6-K	6-K 4-5-G	6-K 4-5-D	6-K 4-5-D	6-K 4-5-I 4-5-G	6-K 4-5-G	6-K 4-5-G	4 M		
Tappers	4-G	4-G	4-D	4-D	4-G	4-G	4-G	4M		
Internal grinding machine	6-C	6-C	6-C	6-C	6-C	6-C		6 C	6 C	6 C
Cylinder and horizontal grinding machines	6-C	6-C	6-C	6-C	6-C	6-C		6 C	6 C	6 C
	6-B	6-B	6-B	6-B	6-B	6-B	6-B	6 B	6 B	6 B
Lapping machines	6-H	6-H	6-H	6-H	6-H	6-H				
Honing machines	6-J	6-J	6-J	6-J	6-J	6-J				
Broaching machines	6-E	6-E	6-D	6-D	6-D	6-D	6-E	6-E		
Power saws	6-K	6-K	6-K	6-K	6-K	6-K	6-K			
Draw presses	6-G						6-G			
Punch presses							6-G			

Operations

1. Heavy cutting.
2. Light cutting.
3. Threading.
4. Tapping.
5. Reaming.
6. General operations.

Cutting Fluids

A. Air.
B. Soda ash—water—lard—light.
C. Soda ash—water—lard—heavy.
D. Mineral—lard oil—11 per cent.
E. Mineral—lard oil—5.5 per cent.
F. Kerosene—mineral oil—10.0 per cent.
G. Sulphurized mineral oil—1 per cent S.
H. Sperm oil.
I. White lead—lard oil—30 per cent.
J. Kerosene.
K. Water emulsions.
L. Vacuum.
M. Petrolatum or cup grease.

[1] J. G. Roney and G. L. Sumner of the Westinghouse Electric & Mfg. Co.

A cutting lubricant or coolant is best determined by cutting action of material and machine on which threading is done. On steel a loss in production and tool upkeep often offsets the difference in price between a good coolant and a cheaper one.

ESTIMATING MACHINING TIME

These speeds and feeds will be found conservative for average work with high-speed steel tools.

TABLE OF CUTTING SPEEDS FOR ESTIMATING PURPOSES

MATERIAL	CUTTING SPEED IN FEET PER MINUTE
Cast iron	50–60
Cast steel	60
Malleable iron	70
Machine steel forgings (15- to 20-point carbon)	60–70
Machine steel bar stock	60–70
Tool steel forgings	35–40
Steel alloys containing nickel and chromium	30–50
Yellow brass	150–200
Composition brass	120–150
Bronzes—manganese and phosphor bronzes usually require speeds approximating those for cast iron. Speed depends considerably on whether lubricant is used or not	30–80
Aluminum—aluminum alloys usually cut freely with lubricant, but the nature of the alloy and the shape of the tools are important factors	150–300

Stellite tools will run satisfactorily at greater speeds and with coarser feeds in the majority of cases.

It is difficult to give thoroughly reliable data on feeds, but a few examples may be of interest. For estimating purposes, and always assuming that the normal finish allowance is provided, the following notes may be used as a basis in setting feeds. There are so many factors to be taken into consideration, however, that variations of from 20 to 30 per cent from the figures given are often correct under certain conditions.

Cast Iron

For roughing cuts on diameters up to 8 inches, the feed may range from $\frac{1}{32}$ to $\frac{1}{16}$ inch. Feeds for finishing cuts may be about the same, and the speeds increased 25 per cent or more, or the feeds may be doubled, using a slight increase of speed and broad-nosed tools. On diameters where the finish allowance is from $\frac{1}{4}$ to $\frac{3}{8}$ inch, the feeds for roughing cuts may vary from $\frac{1}{16}$ to $\frac{1}{8}$ inch, and for finishing cuts higher speeds can be used with finer feeds, or slower speeds with an increase of feed, if broad-nosed tools are used. On large work, final finishing cuts are sometimes taken at cutting speeds 50 per cent higher than for roughing cuts, and with a feed of from $\frac{1}{2}$ to $\frac{3}{4}$ inch per revolution with very broad-nosed tools and when great accuracy is not required. These statements are based on actual practice, and, although they cannot be considered as positive in their nature, they will be found to answer very well for a great proportion of cast-iron work.

Cast Steel

Roughing cut feeds on diameters up to 8 inches will vary from 0.020 to 0.040 inch. Finishing feeds should be decreased by 25 to 50 per cent, while speeds can be correspondingly increased. For larger diameters, where the finish allowance is from $\frac{1}{4}$ to $\frac{5}{16}$ inch, the feeds for roughing may vary from 0.040 to 0.060 inch, and for finishing cuts on large diameters, where considerable accuracy is required, the feeds should be 50 per cent finer with speeds increased 25 per cent or more. Broad-nosed tools cannot be used to advantage for finishing steel castings, as they are inclined to tear the metal and leave it rough. The use of lubricant is assumed when cutting steel castings, and the tools must be lipped and ground to suit the material.

Malleable Iron

Roughing cuts on diameters up to 8 inches can be made with feeds from $\frac{1}{32}$ to $\frac{1}{16}$ inch, and finishing feeds are about the same as for cast iron. The use of lubricant for malleable iron is recommended.

Machine-Steel Forgings

The feeds will range from 0.020 to 0.040 inch for roughing cuts on diameters up to 8 inches. For finishing, the feeds should be decreased from 20 to 30 per cent, and the speeds can usually be increased from 30 to 50 per cent. For larger diameters, when the finish allowance is considerably greater, the maximum feed can seldom be over $\frac{1}{16}$ inch, and in many cases not more than $\frac{1}{32}$ inch is permissible. Finishing cuts on large diameters are generally about the same as for cast steel, always assuming that a plentiful supply of lubricant is provided.

Machine-Steel Bar Stock

It is difficult to give feeds on this class of work, because diameters are frequently reduced by taking a very deep cut with a fine feed, but when box tools or universal turning tools are used, and when the stock reduction is not more than $\frac{3}{16}$ to $\frac{1}{4}$ inch, a feed of from 0.020 to 0.040 inch can often be used. In forming cuts and for greater stock reductions, the feeds may vary from 0.002 to 0.015 inch, depending upon the shape of the form to be cut and the method of applying the tools. Finishing cuts are seldom made with a coarse feed, but speeds are increased in many cases as much as 50 per cent.

Tool-Steel Forgings

Roughing cuts on small diameters up to 6 or 8 inches with a depth of cut not exceeding $\frac{1}{4}$ inch can usually be machined with feeds from 0.012 to 0.020 inch, and occasionally a feed of 0.030 inch can be used, if the forgings have been thoroughly pickled and annealed. For finishing cuts, the feeds must be finer, although the speeds can usually be increased about 25 per cent. On large diameters, feeds from $\frac{1}{32}$ to $\frac{3}{64}$ inch are possible in some cases, when the depth of the cut does not exceed $\frac{3}{8}$ inch, but in estimating work of this kind it is seldom safe to exceed a feed of $\frac{1}{32}$ inch for roughing cuts. Finishing cuts for large diameters can be slightly coarser, if great accuracy is not required in the product and if the appearance of the work is not of primary importance. Otherwise fine feeds must be used and the tools "lipped" to curl the chip, in order to remove the metal easily and leave the surface smooth and clean. Lubricant must always be used on this kind of work and any boring tools for deep holes must be designed so that lubricant can be carried to the cutting edges.

Steel Alloys

Roughing cut feeds are usually about the same as for tool steel forgings. It is safe to follow the procedure noted in the preceding paragraph, unless it is possible to obtain a sample of the alloy on which tests can be made to determine the feeds and speeds possible.

Yellow Brass

For roughing cuts on work up to 8 inches in diameter and having a finish allowance of from $\frac{1}{16}$ to $\frac{1}{8}$ inch, feeds from 0.020 to 0.040 inch can be safely used. It is not advisable to go much beyond these feeds, as there is danger of tearing the metal, so that the finishing cuts will not remove the marks made in roughing. For finishing cuts, tools should be ground with a "drag," and, when only a small amount is allowed for the finishing cuts, the feeds can be quite coarse, even with very high speeds. For roughing cuts on large diameters when the finish allowance does not exceed $\frac{1}{4}$ inch, feeds as coarse as $\frac{1}{16}$ or even $\frac{3}{32}$ inch can be used in extreme cases. It is not advisable, however, to attempt to use too coarse feeds for the reason previously stated. In finishing large diameters, the same rule applies as that mentioned for small diameters, that is, coarse feeds and high speeds, provided the tool is ground with a drag. Some operators prefer to use finer feeds in finishing, but this is not necessary if judgment is used in grinding tools.

Composition Brass

Roughing and finishing cuts are approximately the same as for yellow brass, although they should be slightly more conservative, as the composition is generally somewhat harder than ordinary brass.

Bronzes

For roughing work up to 8 inches in diameter where finish allowances do not exceed $\frac{1}{16}$ to $\frac{3}{32}$ inch on a side, feeds from 0.020 to 0.040 inch can generally be used, depending considerably on the nature of the alloy. Phosphor bronze and manganese bronze are hard in their composition and the feeds used must not be too great. In addition to this, the scale on bronze castings is extremely hard and has a strong abrasive action on the tools, so that they dull very rapidly. The speeds and feeds used in finishing can be considerably increased, but if good work is required, it is not advisable to use very coarse feeds, and an increase of 25 per cent over the roughing cuts will usually be found satisfactory. For larger diameters, when the finish allowances approach ¼ to 5/16 inch, the feeds for roughing can frequently be 0.030 to 0.060 inch. In finishing large diameters slightly coarser feeds can be used than for the smaller sizes, but really coarse feeds cannot be applied to advantage if a good finish is desired.

Aluminum

The feeds for roughing this class of material vary greatly on account of the difference in the composition of the alloy. In general, very coarse feeds can be used for both large and small diameters, provided the tool is suitably ground. The writer has seen aluminum castings 10 inches in diameter machined dry at a cutting speed of 300 feet per minute and with a feed of ⅛ inch per revolution. It would not be advisable, however, to use speeds and feeds of this kind for estimating, because the nature of the alloy might easily make a great difference. Feeds for the majority of roughing cuts on small diameters, when the finish allowance is approximately ⅛ inch, can vary from 0.040 to 0.080 inch, and in extreme cases even more than this. Finishing cuts are possible at feeds from ⅛ to ½ inch per revolution, when broad-nosed tools are used. For large diameters an increase of about 25 per cent is permissible, in both roughing and finishing. It is advisable to be somewhat conservative in setting feeds for this class of work, but it will, in general, be found that the production time is much better than the estimated time, provided the operator uses judgment and tries to obtain the highest possible production.

Boring and Drilling in the Ford Plant

SINGLE-POINT BORING—FORD V-8 CYLINDERS

Metal removed	0.014 inch
Roundness and straightness	0.0002 inch
Bores per grind of tool	500
Speed: 520 revolutions per minute or 430 feet per minute	
Feed	0.007 inch per spindle revolution

DRILLING—FORD

Bronze	250 feet per minute
Copper	150 feet per minute
Aluminum	300 feet per minute
Malleable iron	80 feet per minute
Cast iron:	
Machined surface	100 feet per minute
Scale surface	80 feet per minute
Deep holes	80 feet per minute
Steel:	
Brinell 402 to 404	40 feet per minute
Brinell 302 to 387	50 feet per minute
Brinell 202 to 293	60 feet per minute
Brinell 101 to 196	70 feet per minute
Brinell less than 100	80 feet per minute

FEED PER REVOLUTION—FORD

1/16	1/8	1/4	3/8	1/2	5/8	3/4	1	1¼, 1½, 1¾, 2, 2½, 3
0.003	0.004	0.006	0.008	0.010	0.011	0.012	0.014	0.016

Power for drilling steel is about 2½ times that for cast iron.
Power for feeds in steel is about 2 times that for cast iron.

CAST IRON

Power for drills...	1/8	1/4	1/2	3/4	1	1¼	1½	1¾	2	2½	3
Horse-power......	0.14	0.29	0.57	0.87	1.16	1.45	1.74	2.03	2.32	2.9	3.5

Steel...............	0.36	0.72	2.85	4.27	5.70	8.55
Feed horse-power for cast iron..........	0.0045	0.0059	0.0071	0.0078	0.0084	0.0093
Feed horse-power for steel.............	0.0081	0.0109	0.0130	0.0145	0.0155	0.0171

TABLE 6.—STANDARD SHAPER TIME TABLES—CUTTING

For all cuts except keyways

Length of Stroke Cut	1/16 Inch, Rough Cut 0.062-In. Feed		1/8 Inch, Rough Cut 0.037-In. Feed		1/4 Inch, Rough Cut 0.025-In. Feed		1/64 Inch, Finish C.I. 0.200-In. Feed		Finish, Cut, 0.025-In. Feed		Head Feed, Rough 0.020 In.		Head Feed, Finish 0.010 In.	
	Strokes per Minute	Time per 1 Inch Tool Travel	Strokes per Minute	Time per 1 Inch Tool Travel	Strokes per Minute	Time per 1 Inch Tool Travel	Strokes per Minute	Time per 1 Inch Tool Travel	Strokes per Minute	Time per 1 Inch Tool Travel	Strokes per Minute	Time per 1 Inch Tool Travel	Strokes per Minute	Time per 1 Inch Tool Travel
In.	118	0.13	83	0.33	83	0.48	27	0.19	118	0.34	118	0.42	118	0.85
2	118	0.13	83	0.33	83	0.48	27	0.19	118	0.34	118	0.42	118	0.85
3	118	0.13	83	0.33	83	0.48	27	0.19	118	0.34	118	0.42	118	0.85
4	83	0.19	59	0.46	83	0.48	27	0.19	118	0.34	83	0.60	118	0.85
5	83	0.19	59	0.46	83	0.48	27	0.19	118	0.34	83	0.60	118	0.85
6	59	0.27	40	0.68	59	0.68	27	0.19	118	0.34	59	0.88	118	0.85
7	59	0.27	40	0.68	59	0.68	27	0.19	83	0.48	59	0.88	83	1.20
8	40	0.40	40	0.68	40	1.00	27	0.19	83	0.48	40	1.25	83	1.20
9	40	0.40	27	1.00	40	1.00	27	0.19	83	0.48	40	1.25	83	1.20
10	27	0.59	27	1.00	40	1.00	19	0.26	59	0.68	27	1.50	59	1.70
11	27	0.59	27	1.00	27	1.40	19	0.26	59	0.68	27	1.50	59	1.70
12	27	0.59	19	1.41	27	1.40	19	0.26	59	0.68	27	1.50	59	1.70
13	27	0.59	19	1.41	27	1.40	19	0.26	40	1.00	27	1.50	40	2.50
14	19	0.85	19	1.41	27	1.40	19	0.26	40	1.00	19	2.63	40	2.50
15	19	0.85	19	1.41	19	2.10	19	0.26	40	1.00	19	2.63	40	2.50
16	19	0.85	19	1.41	19	2.10	19	0.26	40	1.00	19	2.63	40	2.50
17	19	0.85	19	1.41	19	2.10	19	0.26	40	1.00	19	2.63	40	2.50
18	19	0.85	13	2.07	19	2.10	19	0.26	40	1.00	19	2.63	40	2.50
19	13	1.24	13	2.07	19	2.10	13	0.38	27	1.48	13	3.90	27	3.70
20	13	1.24	13	2.07	19	2.10	13	0.38	27	1.48	13	3.90	27	1.48
21	13	1.24	13	2.07	13	3.08	13	0.38	27	1.48	13	3.90	27	1 48
22	13	1.24	13	2.07	13	3.08	13	0.38	27	1.48	13	3.90	27	1.48

Finish Cut Based on $\frac{1}{32}$-Inch Depth
Table Based on Cutting of Cast Iron

CONVERSION FACTORS FOR OTHER MATERIALS

	M. S. & M. I.	Forg St.	Br. Cu.	Tool Steel
Cut	1	1	1	2
Cut-Off or Part	3	3.9	2.1	6

TABLE 7.—STANDARD SHAPER TIME TABLES—SETUP

JOB ALLOWANCES, IN MINUTES		
Per Job:		
Table setup		8
Simple vise setup		5
Dividing head		10
Angle iron		8
Simple fixture		10
Complex		15
Diff. fixture		35
Large angle plate		8
Small angle plate		7
V-blocks		7
Set Tool on First Piece:		
This will be used mostly on keyways and slots	plain medium difficult	2 3 5
Tool Adjustment per cut:		
*Change tool and set cut with measure		1.20
*Set first cut with measure same tool		0.85
Raise tool by head feed (rough)		0.10
and start next cut (accurate)		0 18
Raise tool by head feed and return table for next cut		0.30
Shift head		0.35

* RATE SETTER'S NOTE.—These two units can be applied in the setup or in the per piece time, depending on the job requirements.

MEASURING ALLOWANCES, IN MINUTES			
Per Piece:			
Using scale	simple medium	0.25 0.5	
Using micrometers		1	
Using verniers		1.5	
Using bevel protractor		2	
Using indicator	simple medium difficult	1 2 5	
Using gage		0.5 1 2	
Level and Square Up:			
+/—$\frac{1}{64}$ inch		0.25 0.5 1	
+/—0.010 inch		1 1.5	
+/—0.005 inch		3	
+/—0.0005 inch		3	
Place, Remove, and Handle per Piece:		Rough	Finish
Vise		0.50	0.75
Shift piece in vise or		0.25	
Shift piece on angle (one bolt)		0.25	
1. Straight clamp or bolt		0.75	0.95
2. Straight clamp or bolt		1.25	1.50
3. Straight clamp or bolt		1.75	2.00
4. Straight clamp or bolt		2.25	2.50
1. C clamp		0.90	1.15
2. C clamp		1.64	1.89
3. C clamp		2.38	2.63
4. C clamp		3.12	3.40
Extra C clamp		0.50	
Extra-straight clamp		0.65	
Jacks 1		0.15	0.30
2		0.35	0.55
3		0.55	0.80
4		1.00	1.50

TURRET LATHE SPEEDS AND FEEDS

Warner and Swasey recommend the speeds and feeds in Table 8 for turret-lathe work, as a general guide for average work.

TABLE 8.—PROPER SPEEDS AND FEEDS FOR TURRET LATHES

Speeds and feeds are altered by type and condition of machine, type of steel used, method of mounting, lubricant used for cutting, material cut, method of holding.

Material	Surface Feet per Minute						Feeds			
	H. S. S.‡		J Stellite		Carbide		Ram-Type Machine		Saddle-Type Machine	
	Rough	Finish	Rough	Finish	Rough	Finish	Rough	Finish	Rough	Finish
Cast iron	50 to 60	80 to 110	90 to 120	130 to 160	180 to 200	350 to 400	0.016 to 0.025	0.016 to 0.025	0.032 to 0.060	0.032 to 0.125
Semisteel, hard	40 to 50	65 to 90	75 to 100	100 to 130	140 to 160	250 to 300	0.016 to 0.025	0.016 to 0.025	0.032 to 0.060	0.032 to 0.125
Malleable iron*	80 to 100	110 to 130	120 to 140	150 to 200	250 to 300	400 to 500	0.016 to 0 025	0.016 to 0 025	0.032 to 0.060	0.032 to 0.060
Steel casting (0.35 carbon)*	45 to 60	70 to 90	70 to 80	90 to 130	150 to 180	200 to 250	0.010 to 0.020	0.012 to 0.020	0.018 to 0.030	0.018 to 0.045
Brass (commercial 85-5-5)	200 to 300	200 to 300			600 to 1000	600 to 1000	Maximum Feed of Machine			
Bronze (80-10-10)*	110 to 150	150 to 180			600	1000	0.016 to 0.030	0.010 to 0.016	0.016 to 0.050	0.010 to 0.030
Aluminum†	400	700			800	1000	Fine Feeds to Produce Good Finish			
S.A.E. 1020 (coarse feed)	60 to 80	60 to 80			300	300	0.020 to 0.030	0.020 to 0.030	0.024 to 0.044	0.024 to 0.044
(fine feed)	100 to 120	100 to 120			450	450	0.007 to 0.020	0.007 to 0.020	0.010 to 0.030	0.010 to 0.030
S.A.E. 1035	75 to 90	90 to 120			250	250	0.020 to 0.030	0.020 to 0.030	0.024 to 0.044	0.024 to 0.044
S.A.E.-X-1315	175 to 200	175 to 200			400 to 500	400 to 500	0.010 to 0.015	0.010 to 0.015	0.010 to 0.015	0.010 to 0.015
S.A.E. 1050	60 to 80	100			200	200	0.012 to 0.020	0.012 to 0.020	0.025 to 0.090	0.015 to 0.045
S.A.E. 2315	90 to 110	90 to 110			300	300	0 012 to 0 020	0.012 to 0.020	0.025 to 0.090	0.015 to 0.045
S.A.E. 3150	50 to 60	70 to 90			200	200	0.012 to 0.020	0.012 to 0.020	0.025 to 0.090	0.015 to 0.045
Stainless steel (selenium content)	100 to 120	100 to 120			240 to 300	240 to 300	0.010 to 0 015	0.010 to 0 015	0.010 to 0 015	0.010 to 0.015

* Water-soluble oil lubricant. † Kerosene lubrieant. ‡ Cobalt 18-4-1.

ADVANCES IN TURNING PRACTICE

Two wartime developments in turning practice have been the wide use of carbide tools on steel and of tools with negative rake both for plain turning and especially for interrupted cuts. As with the new milling practice, the real advantage of the negative rake is the protection of the cutting edge of the tool. This is especially true in work with interrupted cuts, as it brings the first contact, or blow, behind the point of the tool where it is well supported.

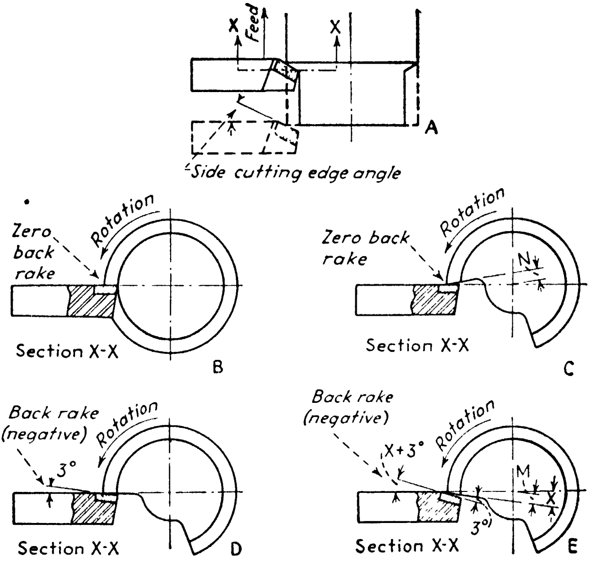

FIG. 13a.—Zero and Negative Rake Turning Tools.

In all high-speed work it is necessary to have the tool rigidly supported, a uniform feed, and sufficient power to pull the cut. Bearings and slides must be well fitted to prevent vibration. Tool shanks should be heavy, particularly on interrupted cuts, and steels that resist bending are recommended.

The effect of back rake on cuts of different types can be seen in Fig. 13a. As seen at *A*, the side cutting angle protects the point by having the first contact with the work about the center of the carbide tip. The other illustrations show different conditions depending on the shape of the tool and of the work as it makes contact. In plain turning, as at *A* and *B*, some consider the zero rake desirable, while others prefer negative rake in nearly all cases where the cut is very heavy.

Illustrations *C*, *D* and *E* show different contacts with interrupted cuts in which the angle of contact varies with the work itself. Here an angle of 3 degrees is preferred. Others prefer greater angles. The main object is to secure a shear cut beginning behind the cutting point. This has been very successful in machining armor plate for tanks and elsewhere. One difficulty in turning armor plate is the tendency to work harden so that tools should be as free cutting as possible. Armor plate castings also flex rather easily under pressure and return to shape after pressure is released.

In comparing turning and milling cutter speeds it must be remembered that in milling each tooth is free of the work for a portion of the time, while in turning there is constant contact, except in intermittent cuts. The nose of a turning tool, buried in the work, inevitably heats far more than the tooth of a milling cutter.

Higher turning speeds can be used on many old machines if their bearings and other moving parts are in good shape. It is frequently only a question of having sufficient power to remove the metal at the high rate. It is also necessary to consider the relative importance of the cutting time as compared to the total time needed on the work. On short cuts, such as many turret lathe jobs, the time for handling the work is greater than the cutting time, so that the total time may not be materially reduced by speeding up the cut. In such cases it is often possible to shorten the handling time by using faster working chucks and fixtures. In many cases cutting speeds can be greatly increased, but experiment is necessary to determine the best speed for the particular job and for the machine being used.

GENERAL MACHINING OF NONFERROUS METALS AND OTHER MATERIALS

The growing use of such nonferrous alloys as aluminum, magnesium, and monel metal and of the various plastics, frequently grouped under the head of bakelite, makes it seem advisable to group the suggestions from various sources, as to tools and methods of machining these, under one heading. This seems to be more convenient than to divide the information among the sections dealing with the various operations to be performed.

Tools for High-Nickel Alloys

Correct combinations of tooling, speeds, feeds, and cutting compounds give satisfactory results in machining such materials as monel, nickel, and Inconel. Monel contains approximately two-thirds nickel and one-third copper. Inconel is approximately 78 per cent nickel, 14 per cent chromium, 6 per cent iron, 2 per cent other elements.

Tungsten high-speed steels of the 18-4-1 type, with 0.70 to 0.75 per cent carbon content, are most satisfactory for general machining. Tools should be of 58 to 60 Rockwell C hardness for machining operations where cutting is intermittent and the tool is subjected to impact and for heavy roughing. For light smooth lathe turning and for automatic machining, tools with 61 to 63 Rockwell C hardnesses are best. For light cuts and high-speed machining, the super high-speed steels, containing cobalt and molybdenum, give best results.

Because of high heat generated in machining high-nickel alloys, carbon tool steels are not satisfactory. Stellite, tungsten, carbide, and tantalum carbide, properly used, are best. Grind with a slightly larger true rake angle than for mild steel. Figures 14, 15, and 16 show tools for various operations on high-nickel alloys.

In machining the harder alloys, Inconel, and K monel, the clearance angle should be kept at a minimum. On heavy, rough machining, it is best to grind a land about $\frac{1}{32}$ inch wide at the cutting edge.

Rough turning, rough planing, and shaping may be done dry, but it is essential to use a cutting oil for all other cutting operations. This increases the machining speed from 25 to 50 per cent, and results in a smoother finish.

Sulphurized oils give best results. Any tarnish is readily removed by soaking the work for 20 to 30 minutes in a cold 10 per cent solution of sodium cyanide.

All lubricants should be thoroughly removed from the machined pieces if they are to be subjected to high temperatures either during subsequent fabrication or in service.

Automatic Screw Machine Work.[1]

In Table 9 are recommended speeds and feeds for automatic screw machine turning on R monel.

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[1] W. F. Burchfield, Research Department, International Nickel Company.

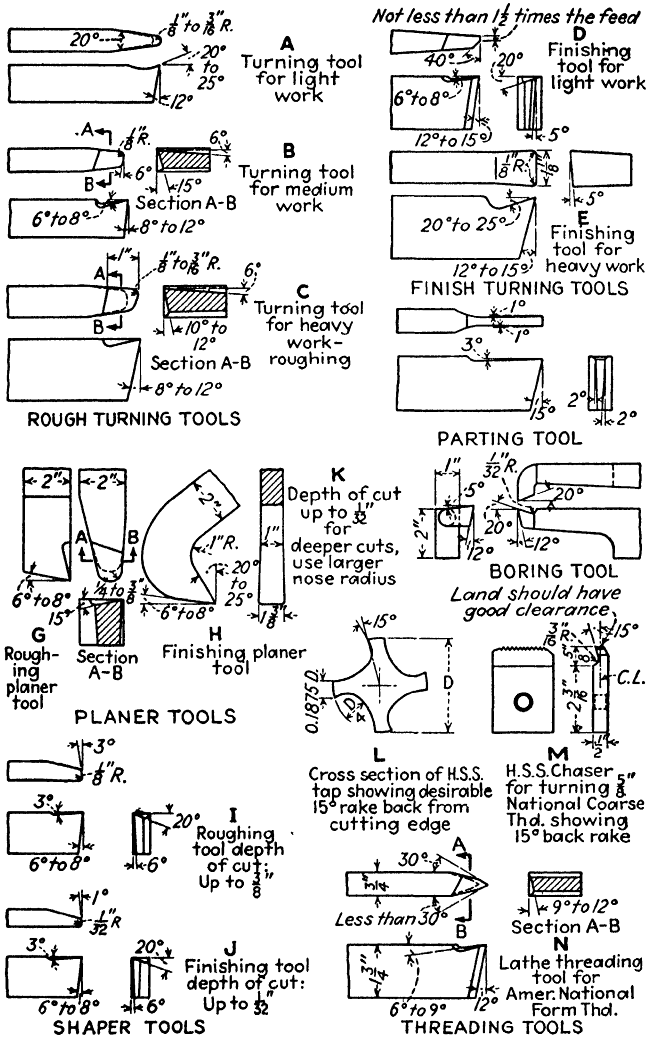


FIG. 14.—Tools for High-Nickel Alloys

Standard twist drills have proper angles for general-purpose work. Only high-speed or super high-speed steel drills should be used, with polished flutes. Sulphurized cutting oils give best results. Recommended speeds for regular monel and nickel are between 40 to 60 feet per minute with the same feeds for mild steel. R monel may be drilled at a speed of 60 to 75 feet per minute. Lower the drilling speed to 30 to 45 feet per minute for Inconel and to 20 to 30 feet per minute with 75 per cent standard feed for soft K monel.

TABLE 9.—RECOMMENDED SPEEDS AND FEEDS FOR AUTOMATIC SCREW MACHINING OF GRADE R MONEL

Operation	Width of Cut, in Inches	Feed, in Inches	Speed, in Feet per Minute
Box tool:			
Roughing	$\frac{1}{32}$	0.006	125
	$\frac{1}{16}$	0.005	125
	$\frac{1}{8}$	0.004	125
Finishing	0.005	0.010	125
Cut-off:			
Circular tool Straight tool	$\frac{1}{16}$ to $\frac{1}{8}$	0.001	125
Stock under $\frac{1}{8}$ inch diameter		0.0005	125
Forming tool:			
Circular	$\frac{1}{8}$ to $\frac{1}{4}$	0.0006	125
	$\frac{3}{8}$ to $\frac{1}{2}$	0.0005	125
	$\frac{5}{8}$ to $\frac{3}{4}$	0.0004	125
	1	0.00025	125
Balance turning tool:			
Turned diameter under $\frac{1}{32}$ inch	$\frac{1}{32}$	0.006	125
	$\frac{1}{16}$	0.005	125
Over $\frac{1}{32}$ inch	$\frac{1}{32}$	0.012	125
	$\frac{1}{16}$	0.010	125

Helical-fluted high-speed steel reamers with narrow lands and well-polished flutes are best. Reamers must be kept sharp. Speeds for reaming are 25 to 35 feet per minute for monel and nickel and 10 to 15 feet per minute for K monel and Inconel. Reaming feeds are about twice the drill feed for the same size hole.

Thread chasing should be done with self-opening dies, which should have a 15-degree hook, as shown in *M*, Fig. 14. In thread chasing, turn the rod slightly smaller than standard as the high-nickel materials will flow into the grooves of the dies, giving full size threads. A speed of 20 to 25 feet per minute is suggested for thread chasing monel and nickel. For K monel and Inconel 10 to 15 feet per minute. For R, speeds are 25 to 35 feet.

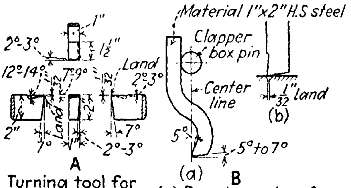
In lathe threading monel, the tool should have a back rake angle of 6 to 9 degrees and a side rake angle of 9 to 12 degrees, as at *N*, Fig. 14. V threads may be machined in monel and nickel at 25 feet per minute with light cuts, and Acme or straight threads at approximately 10 to 15 feet per minute. For K monel and Inconel, reduce these speeds to 15 feet per minute for V threads and to 5 to 10 feet per minute for straight or Acme threads.

In tapping, use a drill of slightly larger diameter than standard National standard, four-fluted high-speed steel, plug taps, with ground threads and 7-degree helical flutes or four-fluted helical pointed plug taps are best for machine tapping. The plug taps have a four- or five-thread chamfer, more is better. The flutes give a 15-degree lip, and the tap should be "backed off." On 1¼ inch and larger sizes, the skip-thread tap gives excellent results.

Regular monel and nickel may be tapped at a speed of 20 to 25 feet per minute; K monel that has not been heat-treated and Inconel at 12 to 15 feet per minute; R monel at 25 to 35 feet per minute in automatic machines.

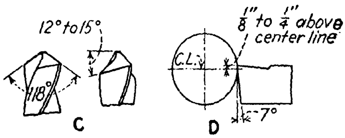
Lathe and Planer Work

The only instruction is that the cutting edge of the tool be set above the center of the work. But, when turning K monel or Inconel with tools ground with a land, the cutting edge of the tool must be set on center.



Turning tool for "K" monel

(a) Broad nose tool for finishing and parting work on deep section on planer
(b) Tool for shaper with small land



H.S. Steel drill standard angles

Method of setting tool ground without land above center of work for lathe work only

DRILL ANGLES LATHE TOOL SET-UP

FIG. 15.—Tools for High-Nickel Alloys

The cuts, feeds, and speeds given for lathe turning in Table 8 are merely guides. They are based on wet cutting and should be reduced 20 to 35 per cent for dry cutting. These speeds must be reduced for boring operations.

The setup for planing or shaping is no different than for mild steel. Roughing is usually done dry, but a cutting oil for finishing cuts and for parting gives a better surface.

Correct designs of planer and shaper tools are shown in Fig. 14 at *G*, *H*, *I* and *J*, and in Fig. 15 at *B*. Table 11 lists some feeds, cuts, and speeds used on production jobs and will serve as a guide in setting up for planing.

Milling chips from these materials do not break up but tend to curl. To facilitate the removal, the cutter should be ground with a 10- to 15-degree back rake from the cutting edge. Coarse-tooth cutters are preferred. Plain or barrel milling cutters should be of the heavy-duty helical-fluted type. Alternating tooth or interlocking side millers are best for deep holes or for slitting. If only straight-tooth milling cutters are available, the sides of the teeth should be cut on a slight taper, widest at the cutting edge. For narrow slotting, high-speed-steel slitting saws with alternate teeth chamfered are most satisfactory. This type of circular saw, which is used for cutting copper, is ground concave on the side for clearance.

For general practice, in milling monel metal and nickel, use an average cutting speed of 50 to 65 feet per minute, with a feed of 0.005 to 0.010 inch per tooth, depending on the depth of cut. With Inconel and K monel that has not been heat-treated, the surface speed of the cutter must be reduced to around 40 feet per minute with a feed of from 0.003 to 0.006 inch per tooth.

TABLE 10.—RECOMMENDED CUTS, FEEDS, AND SPEEDS FOR LATHE TURNING

Cut, in inches	$\frac{1}{64}$	$\frac{1}{32}$	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$
Feed, in inches	$\frac{1}{64}$, $\frac{1}{32}$	$\frac{1}{64}$, $\frac{1}{32}$, $\frac{1}{16}$	$\frac{1}{64}$, $\frac{1}{32}$, $\frac{1}{16}$	$\frac{1}{64}$, $\frac{1}{32}$, $\frac{1}{16}$, $\frac{1}{8}$	$\frac{1}{32}$, $\frac{1}{16}$, $\frac{1}{8}$	$\frac{1}{16}$, $\frac{1}{8}$, $\frac{3}{16}$
Wrought monel nickel	170, 140	115, 100, 85	95, 80, 55	85, 70, 50, 45	55, 45, 35	35, 30, 25
Wrought K monel (unhardened) Inconel	125, 90	75, 65, 50	60, 45, 35	50, 40, 37, 30	35, 30, 25	25, 20, 15

Cutting speeds in feet per minute.

TABLE 11.—FEEDS AND SPEEDS FOR PLANING (HEAVY WORK)

	Roughing Tool, Fig. 7				Finishing Tool, Fig. 8			Parting Tool, Fig. 6
Depth of cut, in inches	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	0.020	0.015	0.010	
Feed, in inches	$\frac{3}{32}$	$\frac{1}{16}$	$\frac{5}{64}$	$\frac{3}{64}$	$\frac{11}{32}$	$\frac{5}{32}$	$\frac{3}{8}$	0.005 to 0.010
Forged monel metal—nickel	25	25	25	25	25	35	30	30
Forged unhardened 2K monel—Inconel	15	15	15	15	15	25	20	20

Cutting speeds in feet per minute.

Monel metal shrinks $\frac{1}{4}$ inch to the foot in castings; should be poured at 2800°F. Cores should be made of washed silica sand and raw linseed oil, about 25:1 for large cores and 60:1 for small cores.

Pickling.—For heavily scaled monel, soak in 10 per cent (by weight) hydrochloric acid for 30 minutes at 180°F., then dip in a sodium dichromate solution for 5 to 10 minutes at room temperatures. This solution is made by dissolving 0.1 gallon of sulphuric (66°Bé.) and 1.1 pounds sodium dichromate in 1 gallon of water. For unscaled monel, use 1 gallon of water, 1.5 gallons of sulphuric acid (66°Bé.), 2.2 gallons of nitric acid (38°Bé.), cool, and add 0.2 pound sodium chloride.

Welding.—Monel metal welds readily by gas or electric method. Monel rods should be used. Welding tip should be one size larger than for steel. An electric welding flux has been specially developed. Monel metal rods make a machinable weld on cast iron. Monel metal is easily soldered and brazed; clear surfaces are necessary.

Drawing and Punching.—Reduction of diameter and depth of draw are about as for steel, but corners of dies should have a larger radius to prevent tearing. Metal is "sticky" and tends to adhere to soft dies. The diameter of the first cup is usually about two-thirds that of the blank. Reduction of 30 per cent in gage may be had in one draw with slight reduction in diameter. Clearances are usually greater than for steel; runs 0.010 to 0.015 inch on metal from 0.1021 to 0.078 inch. Greater power required than with steel. Proper adjustment of pressure plate and blank holder prevents wrinkling. Anneal at 1400 degrees between draws. Punches are designed about 75 per cent stronger than for steel, with same clearance angles.

Spinning.—Owing to toughness, monel metal is harder to spin than copper, brass, steel, or silver and requires more frequent annealing. Spinning tools should be brass, bronze, wood, or tool steel, not soft steel. Lubricate with tallow. No change necessary from ordinary speed of lathe.

Nichrome

Nichrome is a trade name for a specific mixture of nickel and chromium. It retains strength at high heats and resists continued or repeated exposure to heat, as in annealing and carburizing boxes; it also resists nitric, hydrochloric, and sulphuric acids. Its properties are:

Tensile strength	64,000 pounds
Elongation in 2 inches	3½ per cent
Reduction in area	2 per cent
Melting point	2500°F.
Specific gravity	8.06
Weight per cubic inch (cast)	0.29 pound
Brinell hardness	157–187
Rockwell hardness	B-83–94
Scleroscope hardness	30

Nichrome welds readily by arc or flame. Preheating is necessary and the weld surface must be clean. Flux is needed in flame welding, but not in arc. Nichrome cannot be cut successfully with a torch, because it does not oxidize readily; a hack or cold saw is better and cheaper.

Nichrome castings can be machined readily with any good high-speed cutting steel at a speed of about 18 feet per minute. Because of the toughness of the alloy, the tools must be ground with special angles. These particular angles have been worked out, and Fig. 16 shows how tools should be ground for machining and threading Nichrome and Cimet castings.

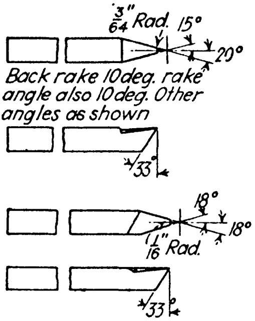

3/64" Rad.
15°
20°
Back rake 10 deg. rake angle also 10 deg. Other angles as shown
1/33
18°
18°
1/16" Rad.
1/33

FIG. 16.—Tools for Nichrome

Machining Aluminum and Its Alloys

Successful machining of aluminum and its alloys requires different tools than for steel and free-cutting brass. The tools should have appreciably more side and top rake than the tools for cutting steel; they should have very keen edges supplemented by hand stoning with an oilstone and used with suitable cutting compounds.

Except for aluminum alloys high in silicon content, carbon steel and high-speed steel tools may be used satisfactorily. Carbon steel tools may generally be maintained with a keener cutting edge. Cemented tungsten carbide tools are necessary for machining the high-silicon alloys, notably "Lo-Ex" No. 132 piston alloy. Carbide tools are also superior to carbon and high-speed steel tools in production because keen edges are maintained over long periods without regrinding. Diamond tools are often used for boring holes where a fine, accurate finish is desirable, such as piston pin holes.

Cutting Speeds.—Aluminum can be machined best by using high speeds and fine to medium feeds. Surface speeds from 500 to 800 feet per minute are possible under some conditions with ordinary carbon steel tools, and appreciably higher speeds with high-speed steel and carbide tools. The feed may vary from ¼ inch for roughing cuts to a few thousandths for finishing cuts. An increase in the amount of metal removed from the stock can often be obtained to better advantage by increasing the speed rather than the feed. The work should be cooled before calipering and finishing to size.

Cutting Lubricants.—For many purposes a soluble cutting oil is good. Ordinary carbon oil or kerosene will often serve but works better when mixed with lard oil, usually in equal parts. For heavy cuts and slow feeds, such as in roughing work or tapping, pure lard oil is good. Cutting compounds of paraffin oil are unsatisfactory. For milling, sawing, and drilling, the soluble cutting oils are satisfactory and more economical than kerosene or kerosene and lard oil lubricants.

Lathe Tools.—Using the round-nosed tool, Fig. 17, the tool should be set to have proper clearance and not curl the chip more than necessary. Before finishing with the tool, its edge should be restoned. Set the tool considerably higher on the work than when machining brass or steel, preferably on a diameter of the work, making an angle of 45 degrees with the horizontal. The tool shown in Fig. 18 is satisfactory for large diameter work where the tool must be set on or near the center of the work. A much better tool is shown in Fig. 19.

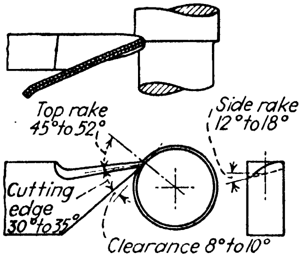


FIG. 17

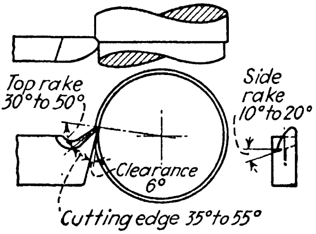


FIG. 18

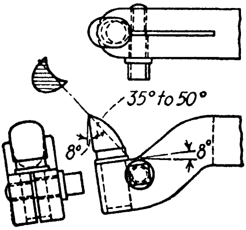


FIG. 19

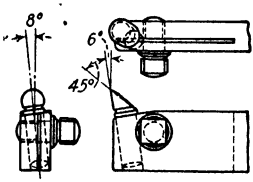


FIG. 20

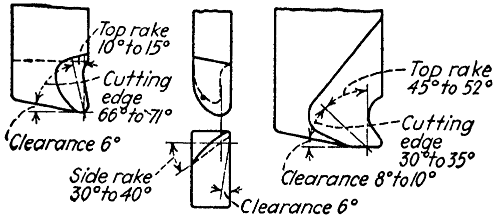


FIG. 21

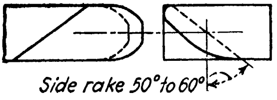


FIG. 22

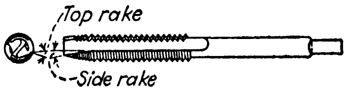


FIG. 23

FIGS. 17 to 23.—Cutting Tools for Aluminum

Resharpen by holding the bit by its shank in the chuck or collet of a tool grinder or a lathe and grinding outside diameter. After each grinding, the tool should be stoned. The bit in the holder may be rotated to various positions and adjusted to different working conditions. This form may be used for both rough turning and finishing cuts. Parting tools should have from 12 to 20 degrees top rake and be stoned. Front clearance angle should be decreased to about 3 or 4 deg. Facing tools should have a side rake similar in amount to the top rake of the outside tools.

Planer and Shaper Tools.—The tool in Fig. 19 may be adapted to planer and shaper work by using a holder, Fig. 20. This tool may be used for both roughing and finishing. For heavy roughing cuts, a side cutting tool, Fig. 21, can be used. The roughing tool should do nearly all of its cutting on the side of the tool, whereas for finishing work, the cutting should be done with the front or bottom edge of the tool. Finishing tool, Fig. 22, should be used for light cuts with fine feeds only.

Milling Cutters.—Milling cutters, straddle mills, end mills, and similar cutters work to best advantage if they are of the coarse-tooth helical type and have considerable top rake. Milling cutters with nicked teeth assist in decreasing the chip size. Inserted tooth face-milling cutters should be designed with appreciable top and side rake. Helical milling cutters work well if the cutting edges are provided with suitable top rake.

Threading Tools.—It is desirable for threading dies or thread chasing tools to provide special rake and clearance. Threads may be chased in the softest aluminum, using a single-pointed threading tool with considerable top and side rake. Hand and machine taps will produce smooth and accurate threads if they have helical flutes. Such taps should have a right-hand helical flute when intended to cut a right-hand thread. The gun tap, Fig. 23, will often work satisfactorily when there is room for the chips to be forced ahead of the tap. Slightly oversize taps assist in maintaining required dimensions of holes in aluminum and its alloys. Thread chasers for self-opening dieheads and collapsible taps should be ground with appreciable top and side rake. Generally speaking, tapping speeds are slow and depend upon the size of the tap drill used, the depth of the tapped hole, and the alloy tapped. In some cases, tapping speeds approximately equal to those used for steel may be used. Screw machine products are generally provided with about 67 per cent of full thread.

Twist drills sometimes give trouble. They should have keen edges and a copious amount of cutting compound. For some work, the single-fluted twist drills are superior to the usual form of drill. Drills with a sharp helix angle work well. Reamers with helical flutes are best.

Saws.—Saw teeth should have considerable top rake and some side rake. Saws of the alternate side-rake type or those of the chip-breaker type (teeth of alternate square and rounded front profile) may be used. A side rake of 15 degrees is recommended for the former. For either type, a front or top rake of 10 to 25 degrees is recommended. To use a saw with much front rake, the sawing machine must be provided with a positive feeding device to prevent the saw from feeding into the work too rapidly.

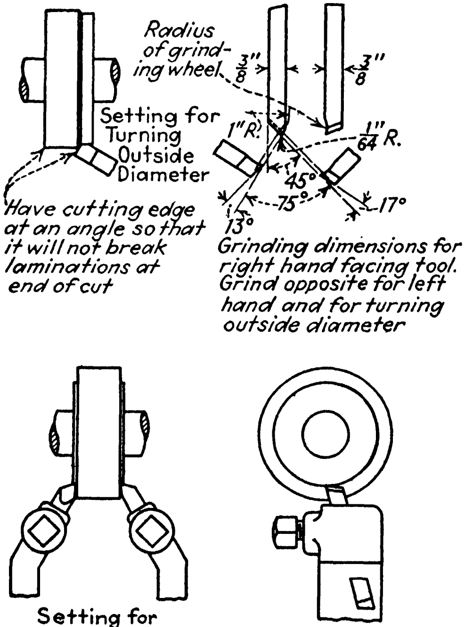
Machining Nonmetallic Materials

GENERAL

Cemented-carbide tools are preferred for machining Formica, Micarta, and Textolite because these materials are abrasive. High-speed steel tools are frequently used for small-quantity work, but carbon steel tools are not employed. Diamond tools are rarely used. Coolant is seldom applied, but an air blast has some cooling effect for drilling operations and is useful in removing chips and dust in this and other operations.

FORMICA

Formica is a laminated gear material made by the Formica Insulation Company, Cincinnati, Ohio. The material is made of cotton duck impregnated with a phenolic resin.


Radius of grinding wheel
3/8"
3/8"
Setting for Turning Outside Diameter
1"R.
1/64" R.
45°
75°
17°
13°
Have cutting edge at an angle so that it will not break laminations at end of cut
Grinding dimensions for right hand facing tool. Grind opposite for left hand and for turning outside diameter

Setting for Facing Side

Side Elevation

FIG. 24.—Tools for Formica and Similar Materials

Turning.—The outside diameter and sides of gear blanks are turned with the tools in Fig. 24. Such tools must have 3 to 5 degrees more rake and clearance than are common for metal turning tools. Speeds up to 750 feet per minute can be used successfully. Cut can be from $\frac{1}{16}$ to ⅛ inch, but the feed should be 0.030 inch, regardless of the cut. The tool should overlap the feed. Provision should be made in grinding the tools so that they clear themselves.

Threading. Chasing tools require special rake and clearance from 3 to 5 degrees more than is common practice with metal. Dieheads do not require special rake and clearance. They are operated at a relatively slow speed and are backed off a short distance in every inch of threading. Neither taps nor dies require special grinding. High-speed and ground taps produce the best results. Tap-drill sizes recommended are the same as those commonly used for metal.

Drilling.—The cutting point of the drill should have an included angle of about 55 degrees. Rapid feed prevents the drill from lagging. For holes more than ½ inch deep, the drill should be withdrawn momentarily to cool and remove the chips. The minimum preferred speed is 1,200 revolutions per minute.

Gear Cutting.—Teeth may be cut on a hobbing or milling machine or a shaper. Assuming a 3-inch hob with 10 teeth, the speed would be 150 feet per minute and the feed from 0.090 to 0.110 inch per revolution.

MICARTA

Micarta is a product of the Westinghouse Electric & Mfg. Co. It is made of either a paper or fabric base and a synthetic resin. The data following are from the company's experience.

Turning.—In general, high speeds, fine feeds, and light cuts are best. If high-speed steel tools are used, the speed should be from 100 to 125 feet per minute. Where roughing and finishing cuts are taken, a high-speed steel tool is not essential for the first operation but should be used for the second. About 0.010 inch of stock should be left for the finishing cut. An exhaust system should be provided.

Threading.—Chasers should be made without the hook used in cutting steel. Plenty of chip clearance should be used on taps and dies as Micarta has a tendency to choke the tap. No undercut or hook on the flute is necessary, but a slight hook on the lead helps to start the chip to curl. High speed taps are preferred except in extremely small sizes. Ground taps are not usually necessary. About 70 per cent full thread is recommended. Standard tap-drill sizes are satisfactory. Small holes (under ¼ inch) are machine tapped at a speed of 200 revolutions per minute, or under. Larger holes are hand tapped. Medium-size holes are tapped with a slow-speed drill press fixture at 40 to 60 revolutions per minute.

Drilling.—Included angle of drill should be 49 to 50 degrees. The face of the lip should have the hook removed as for cutting brass. The grade of Micarta has an effect on the cutting speed and feed. For Micarta with a cloth or paper base, holes up to ¼ inch in diameter can be drilled at a speed of 1,600 revolutions per minute. The asbestos grade requires slower speeds of 800 to 1,000 revolutions per minute. Holes from ¼ to ⅝ inch require speeds from 500 to 800 revolutions per minute. For holes from ⅝ to 1 inch the speed should be from 80 to 200 revolutions per minute, and above 1 inch in diameter, a counterbore should be used. Use hand feed. On small holes and thin material, a feed suitable for wood can be used. When drilling straight through on thick material, it is necessary to clear the drill about every ½ inch.

Milling.—A standard cutter may be used at a speed and feed corresponding to those used for bronze or soft steel.

Punching.—Dies should be designed the same as for punching metal, except that smaller clearances should be allowed. In cold punching, it is desirable that this clearance be small and approach a sliding fit. Maximum punching thickness for any grade is ⅛ inch. Heating the stock from 210 to 250°C. will assure better quality punching.

Sawing.—Material up to 1 inch thick should be cut with a 10-inch saw working at 3,000 revolutions per minute. Above 1 inch thick, a 16-inch saw, running at about 1,600 revolutions per minute, is satisfactory. Roughing cuts should be made with a saw having a bevel tooth, seven to the inch, while for finishing, a smooth saw similar to that used for metal (no set) should be used.

TEXTOLITE

Textolite is a product of the General Electric Company. It consists of canvas coated with a synthetic resin as a binder.

Turning.—The tools used by the company have tungsten-carbide tips mounted on ⅜- or ⅝-inch square bits. These tools are ground with no top rake and with 6½ degrees clearance on the end and sides. A very keen edge must be maintained. When tools become too dull to cut Textolite, they will still work satisfactorily on metals.

The cutting speed is usually the highest speed that the machine will handle, up to 500 or 600 feet per minute. Roughing cuts range from $\frac{1}{16}$ to ⅛ inch, finishing cuts not less than $\frac{1}{64}$ inch.

Threading.—The rake and clearance on chasing tools are the same as those used on turning tools. Special grinding is not necessary for taps and dies. High-speed ground taps have been found to give the best results. Tap-drill sizes are the same as those used for steel. Most work is tapped by hand. For production tapping, it is recommended that a coolant of very light oil or turpentine be used.

Drilling.—Best results are obtained with twist drills having a long lead and with the lips ground thin and with little rake. An air blast is used to cool the drill. Most drilling work is done with hand feed. For a ⅜-inch drill, the speed is 1,800 revolutions per minute. With automatic feed, using a No. 45 drill operating at 3,600 revolutions per minute, a feed per revolution of 0.002 to 0.003 inch has been found satisfactory.

Punching.—Textolite may be punched readily in thicknesses up to ⅛ inch. The die should be relieved on a taper of about ¼ degree to a distance of ⅛ inch below the surface. This relief will minimize splitting around the edge of the punched part. Punched holes usually contract slightly, so that it is necessary to make punches slightly larger than the hole desired. The increase in punch diameter is equal to approximately 3 per cent of the thickness of the material. When thick pieces are being punched, it is desirable to use a shaving die.

Some grades of Textolite can be punched cold, but it is worth while to heat all material before punching. This is usually done by laying the strips on a steam plate which should not have a temperature higher than 300°F. The Textolite should not be left on the plate for an extended period.

HARD RUBBER

Turning.—Shapes of cutting tools are given in Table 12. High-speed steel is recommended for turning tools. Tungsten-carbide tools are used when the savings justify the expense and because they avoid frequent resharpening, improve the finish and accuracy. Where accuracy demands, diamond tools are used, but cannot be employed on interrupted cuts. With coolant, turning, facing, and boring operations can be done at a speed of 300 feet per minute; dry, the speed is reduced to 200 feet per minute. A large screen area should be provided in coolant reservoirs to remove floating rubber particles. It is recommended that wet grinding wheels be used in place of turning wherever possible.

TABLE 12.—TOOL SHAPES FOR HARD RUBBER

Operation	Tool	Top Rake, in Degrees	Side Rake, in Degrees	Clearance, in Degrees	Notes
Turning . .	Steel (lathe)	None	None	10 to 20	If consistency of stock causes tool to tear, tilt forward to increase clearance and provide negative rake of 5 to 10 degrees
	Form tools	None	None	15 to 20	
	Tungsten carbide tip	None	None	10	
Facing. . . .	Roughing diamond	None	None	10	Round nose $\frac{3}{32}$ inch radius
	Finishing diamond	None	None	10	Round nose $\frac{1}{64}$ inch radius
Threading.	Tap	Snub slightly		. . . .	Grind flutes deep as possible.
	Die	Snub slightly		. . . .	
	Diehead chasers	Negative rake, 15 degrees		. . . .	

American Hard Rubber Company.

Threading.—Tables 12 and 13 give information on the grinding of chasers, as well as the speeds recommended. High-speed taps and chasers are preferred. No special table of tap-drill sizes has been developed. When cutting coolant is not available or practical, machine oil should be applied to taps and dies. If the tolerances are very exact the taps should be made 0.002 to 0.003 inch oversize for taps up to No. 6-32; 0.005 to 0.006 inch oversize for taps up to $\frac{3}{8}$ inch; and 0.006 to 0.010 inch oversize for taps from $\frac{3}{8}$ to 1 inch.

Drilling.—Feeds and speeds for drilling are given in Table 13. High-speed drills are preferred. A greater helix angle than with steel increases the cutting speed and drill life. An ideal helix angle is from 35 to 40 degrees, but is available only in small diameters and in drills made by the Cleveland Twist Drill Company. Drill sizes below ¼ inch should be ground to an angle of 45 degrees. Above the ¼-inch size, the standard 59-degree angle is used. The lips should be snubbed or ground flat to prevent digging in. Flat drills may be used for odd sizes or large diameters. The same coolant as applied for tapping should be used.

TABLE 13.—SPEEDS FOR MACHINING HARD RUBBER

Operation	Drilling						
Diameter, in inches	To 3/16	¼	⅜	½	⅝	¾	1
Speed, revolutions per minute	4,000	3,000	2,000	1,550	1,200	1,000	750
Feed, in inches	0.005	0.006	0.008	0.010	0.011	0.012	0.014

	Tapping (Pipe Sizes)			
Nominal size, in inches	Up to 2	2½	3	4
Speed, in feet per minute	200	100	75	55

Turning, Facing and Boring
With no coolant, 200 feet per minute—with coolant, 300 feet per minute

American Hard Rubber Company.

Sawing.—Bandsaws 0.035 inch thick by ⅞ inch wide, 5 to 8 points per inch, running at about 3,400 feet per minute, give good results for rough sawing. For cutting off small rods, tubes, and strips, abrasive wheels, such as the Norton Grain 30 Grade R8 or a Carborundum "Carbo Redmanol" 70C-6V, are suitable. The wheel should be about 8 inches in diameter, 1/16 inch thick, running at 10,000 feet per minute. For sawing panels or sheets, the following saws may be used: a 14 inch diameter by ⅛ inch thick Carborundum 50-C4 or "Carbo Redmanol" 36C-2D wheel running at about 12,000 feet per minute.

Grinding.—Either wet or dry grinding may be done. If hard rubber is ground wet with water or with cutting lubricant, the surface is black and smooth, but if ground dry, the surface will be more or less rough and will be brown in color. Wheels used for various types of work are:

Article	Wet or Dry	Wheel
Penholders—pipe bits	Wet	60 N. Crystolon or Alundum
Rods or tubes	Wet	60 M Crystolon
Rods or tubes	Wet	36 L Staralon
Sheets up to about 1 inch thick	Dry	50 K Silicon
Sheets over 1 inch thick	Dry	24 L Alundum

American Hard Rubber Company.

TABLE 14.—DEPTH OF CUT AND FEED

Surface	Depth of Cut, in Inches	Feed, in Inches	
		Turning	Boring
Rough cut	$\frac{1}{16}$	0.025	0.018
	$\frac{3}{32}$	0.023	0.016
	$\frac{1}{8}$	0 020	0 014
	$\frac{5}{32}$	0.018	0.012
	$\frac{3}{16}$	0.017	
	$\frac{7}{32}$	0.016	
	$\frac{1}{4}$	0 015	
Finish cut	$\frac{1}{32}$	0.012	0.009
	$\frac{1}{16}$	0 012	0.009
	$\frac{3}{32}$	0 011	0.008
	$\frac{1}{8}$	0.010	

American Hard Rubber Company.

FIBER

Turning.—Fiber is an extremely hard and tough material, and tools must be kept sharp to obtain the best results in machining. The material is slightly elastic and tends to impinge against the back of the tool and to generate heat. Generally, tools for cutting fiber should be ground about the same as for cutting brass. The peripheral speed should be about 30 per cent faster than for cast iron, using a coarse feed and a wide-nosed tool. Large clearance, but no rake, should be employed. Lubricant is not needed. Diamond cutting tools are satisfactory for light cuts on close work.

Fiber tubes and rods can be successfully machined in automatic screw machines or hand turret lathes. When tubes of the correct size can be secured, they will generally give better results than rods. The following are the recommended cutting feeds on automatic screw machines:

Drilling	0.007 to 0.010 inches per revolution
Turning	0 010 to 0.015 inches per revolution
Forming	0.0015 to 0.002 inches per revolution
Cutting off	0 002 to 0.003 inches per revolution

Threading.—Both solid and self-opening dies are used, but the self-opening type is best except with short thread lengths where the threads may be torn off in opening the die. A smoother thread is obtained by stoning the dies to a negative rake of 7 degrees and slightly dulling the cutting edge with a V-shaped stone. Tap drill holes should be made from 0.002 to 0.006 in. larger than when tapping brass or steel. Tap drills cut fiber a few thousandths below size unless ground slightly off center. A very little oil will give an easier flow of chips.

Drilling.—Run drills at the highest speed possible without burning the tool. A $\frac{1}{4}$-inch drill should run at 2,500 revolutions per minute, and a No. 60 drill at 10,000 revolutions per minute. High-speed or special bakelite drills with greater helix, narrow web, and wide flutes are recommended. The drill should be ground with a liberal clearance and should not be forced. Fiber should always be drilled perpendicular to the grain when possible. Digging in may be minimized by stoning the cutting edge to give it a slight negative rake.

Milling.—With standard milling cutters, high speeds and feeds give the best results, as to both finish and length of time between grinds. Two-bladed fly cutters for form work should be run at higher speeds but with slower feed. A high speed and coarse feed will throw the chips away from the work and will prevent a rubbing action that dulls tools quickly. For deep slots, use side milling cutters because fiber will bind if straight-side cutters are employed.

Sawing.—A smooth polished edge can be obtained with a hollow-ground circular saw without set to the teeth. A satisfactory circular saw for stock up to ¼ inch is 14 inches in diameter, with 110 to 120 teeth, and from ⅛ to $\frac{5}{32}$ inch thick at the outer edge. The saw should be run at 2,500 to 3,000 revolutions per minute. Bandsaws with 5½ points per inch and 19 gage thickness are satisfactory. The widths vary from ¼ inch for scroll sawing to 1¼ inches for heavy sheet sawing. A bandsaw should run at about 4,000 feet per minute and will last from 1 to 1½ hours on ⅛-inch fiber, and ½ hour on ¾-inch fiber before sharpening is necessary.

Bending and Forming.—Fiber should always be bent parallel to the grain (long way of the sheet), because it is difficult to bend fiber across the grain without breaking. It is general practice to soften the material by immersing in hot or cold water and then drying it out in heated forms under sufficient pressure to keep the shape desired. If the material can be steamed instead of immersed, it will require less time to set.

Punching.—Blanking, piercing, and shaving operations on fiber can be done with ordinary punch presses. The punches should be a close fit in dies for best results. Fairly smooth edges can be obtained in stock up to ⅛ inch thick without heating. Above this thickness it is advisable to heat the stock to 180°F. When a rough edge is not objectionable, thicknesses of ⅜ to ½ inch can be punched. Dies for fiber should not have any taper clearance. Punch will produce a hole 0.001 to 0.008 inch smaller than itself. Blank should be 0.001 to 0.0008 inch larger than the hole in the dieplate, the allowance increasing with the thickness of the stock.

Shaving.—The cutting edge of shaving dies should be about 45 degrees. No clearance is given to the first ¼ inch of the die, and dies can be ground without changing size. A better edge can be had by using a roughing and finishing cutter. Fiber has a tendency to check. Elimination of the difficulty will be obtained by heating it to 180°F. If the cutting edge on a shaving cutter is mouthed out very slightly with an oil stone, the stock will bind slightly in passing through, will prevent chatter, and will tend to smooth and polish the edges. Stock up to 1¼ inches thick can be smooth punched by successive shaving operations.

Stellite J-Metal

The cutting speeds and feeds for turning, facing, and boring, supplied by the Haynes Stellite Company, represent average

TABLE 15.—AVERAGE CUTTING SPEEDS AND FEEDS FOR TURNING, FACING, AND BORING WITH HAYNES STELLITE J-METAL

Type of Cut	Hard Cast Iron		Medium Cast Iron		Malleable Iron	
	Cutting Speed, in Feet per Minute	Feed per Revolution, in Inches	Cutting Speed, in Feet per Minute	Feed per Revolution, in Inches	Cutting Speed, in Feet per Minute	Feed per Revolution, in Inches
Rough turn	60 to 90	0.020 to 0.062	100 to 150	0.020 to 0.125	125 to 175	0.020 to 0.035
Finish turn	150 to 175	0.020 to 0.035	150 to 175	0.020 to 0.050	150 to 200	0.020 to 0.035
Rough face	60 to 90	0.020 to 0.062	100 to 150	0.020 to 0.125	125 to 175	0.020 to 0.035
Finish face	150 to 175	0.020 to 0.035	150 to 175	0.020 to 0.050	150 to 200	0.020 to 0.035
Rough bore	60 to 90	0.020 to 0.062	80 to 150	0.020 to 0.125	100 to 175	0.020 to 0.035
Finish bore	100 to 150	0.020 to 0.035	125 to 175	0.020 to 0.050	150 to 200	0.020 to 0.035
	Steel Castings		S.A.E. 3115		Cold-Rolled Stock	
Rough turn	60 to 125	0.015 to 0.030	125 to 175	0.020 to 0.030	200 to 300	0.020 to 0.035
Finish turn	125 to 200	0.010 to 0.020	150 to 200	0.010 to 0.020	300 to 400	0.010 to 0.020
Rough face	60 to 125	0.015 to 0.030	125 to 175	0.020 to 0.030	200 to 300	0.020 to 0.035
Finish face	125 to 200	0.010 to 0.020	150 to 200	0.010 to 0.020	300 to 400	0.010 to 0.020
Rough bore	60 to 125	0.015 to 0.030	125 to 175	0.015 to 0.030	200 to 300	0.015 to 0.030
Finish bore	125 to 200	0.010 to 0.020	150 to 200	0.010 to 0.020	200 to 350	0.010 to 0.020

practice in production shops. These figures do not apply to any particular job, but can be used as a starting point. Cutting speeds can be increased 30 per cent or more if a coolant is used.

CEMENTED CARBIDE TOOLS

Carbide tools are now being made with tungsten, tantalum, titanium, and other alloys. Generally speaking, the tungsten carbides work better on cast irons than on steel, and titanium and tantalum carbides prove successful on steel. Selection of the proper grade for the work is important in all cases. American practice gives best results with high speeds and light feeds and cuts. Average speeds are given by Carl Pulvermacher of the Ex-Cell-O Corporation as 400 to 425 feet per minute. They cut steel of 520 Brinell at 400 feet per minute. Interrupted cuts on steel may give trouble, but in cast iron they can run up to 900 feet per minute.

TABLE 16.—SOME EXAMPLES OF SPEEDS AND FEEDS WITH CARBIDE TOOLS

Operation	Material	Speed, in Feet per Minute	Feed, in Inches
Turning	Aluminum	1,350	0.014
	Brass	375	0.015
	Bronze	400	0.018, cut $\frac{1}{16}$
	Cast iron	520	0.025, cut $\frac{1}{16}$
	Cast iron	146	0.035, cut $\frac{3}{8}$
	Cast iron	70	0.070, cut $\frac{1}{4}$
	Steel S.A.E. 1040	170	0.003, cut $\frac{1}{4}$
	Steel S.A.E. 4150	300	0.022, cut $\frac{1}{8}$
Milling	Cast iron	222	2.0, cut 0.020
	Cast iron	265	1.9, cut $\frac{3}{32}$
Planing	Semisteel	120	$\frac{1}{16}$, cut $\frac{3}{16}$

CHROMIUM-PLATED TOOLS

Plating tools and gages with chromium has its uses. It builds up worn gages with a very hard surface. It is also used to build up worn reamers to size and increase their useful life. When drill flutes are chromium plated, the chips slide out more easily. Plating surfaces of cutting tools that do not have to be ground increases their life.

Cases are cited where chromium plating the teeth of saws used in cutting insulation from between commutator bars increased the saw life ten times. Chromium-plated twist drills also last much longer in drilling slate and similar material. Some claim they equal tungsten carbide for this work.

DIAMOND TURNING TOOLS

There are relatively few standard diamond tools for turning, cutting, boring, reaming, and facing. These are usually made up to specifications for special operations on plastics, phenoloids, caseins, compressed fiber, rubber, etc., and also on nonferrous alloys such as aluminum, brass, bronze, copper, etc. However, many standard types are made for special industries and crafts, among them, optical, engraving, jewelry, textile, radio, automotive, and electrical. Diamond tools for turning, boring, etc., are mounted with shaped diamonds, ground and polished to any requirements and limited only to sizes in which suitable stones can be obtained. Set two or more in spindles, diamond tools can be used for boring, reaming, and finishing large work. Also they are used regularly for turning large rolls, as, for example, calender rolls for paper-making machines.

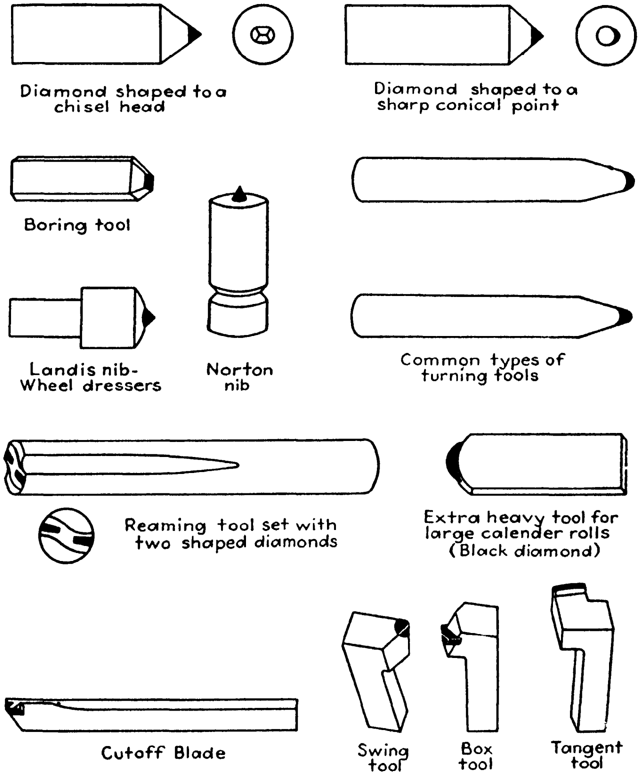

Diamond shaped to a chisel head
Diamond shaped to a sharp conical point
Boring tool
Landis nib-Wheel dressers
Norton nib
Common types of turning tools
Reaming tool set with two shaped diamonds
Extra heavy tool for large calender rolls (Black diamond)
Cutoff Blade
Swing tool
Box tool
Tangent tool

FIG. 25.—Tools with Inserted Diamond Tips

Size limitations are confined especially to special shapes required in single stones. Sometimes diamonds are matched and polished

TABLE 17.—GENERAL DATA ON DIAMOND TOOLS

Operation	Material	Work Size in Inches	Stock Removed	Revolutions per Minute	Pieces per Hour	Pieces before Relapping	Feed	Extra Finishing
Turning roll......	Bearing bronze	$2\frac{1}{2}$ diameter × 18	0.003 to 0.005	1,000	3	Indefinite	Automatic	None
Recessing........	Catalin	$\frac{3}{64} \times \frac{11}{32}$	....	6,500	600	Indefinite	Direct drive	None
Turning.........	Lynite (aluminum alloy)	$4\frac{1}{2}$ long	0.008 to 0.010	2,400	96	Indefinite	Automatic	None
Boring (finish)...	Bronze	$\frac{15}{16}$ diameter	0.008 to 0.010	3,500	160	Indefinite	Automatic	None
Boring (finish)....	Aluminum	1 × 1	0.008 to 0.010	3,400	150	Indefinite	Automatic	None
Turning..........	Copper	2 diameter × 1	0.005 to 0.008	2,000	60	20,000 to 30,000	Automatic	None
Turning..........	Aluminum	$3\frac{1}{2}$ long	0.008 to 0.010	1,100	52	Indefinite	Automatic	None
Facing...........	Hard rubber	$3\frac{1}{4}$ diameter	0.020	3,600	110	4,500	Hand feed	Buffing
Reaming.........	Hard rubber	$\frac{3}{16}$ diameter × $\frac{15}{16}$	0.010	3,600	1,800	50,000	Automatic	None
Reaming.........	Celluloid	$\frac{3}{16}$ diameter × $\frac{15}{16}$	0.010	3,600	700	100,000	Hand feed	None
Turning..........	Celluloid	$\frac{7}{16} \times \frac{5}{8}$	0.008 to 0.010	3,600	1,000	25,000	Automatic	None
Turning rod......	Bakelite	$1\frac{1}{4}$ diameter × $8\frac{3}{4}$ long	0.008	3,500	30	Indefinite	Automatic	None.

Data from Arthur A. Crafts & Co.

to form, and then set in multiples for larger types of forming. On plastics, resinoids, alloys, etc., diamond tools, if correctly designed and used, usually produce a mirror polish in one operation. Only in very unusual cases are further operations like buffing or polishing necessary.

It is next to impossible to establish fixed rules of machine procedure for diamond tools because special equipments, methods, materials, and conditions apply so generally. Some actual case examples of diamond-tool results are shown in Table 17. They are not unusual cases but were taken at random from many shop studies, made recently under average shop conditions and with usual equipment. Figure 25 shows a number of tools with diamond tips.

TUNGSTEN CARBIDE TOOLS

These tools are very useful in machining materials having abrasive qualities, such as fiber and hard rubber. On this kind of work the tool life between grinds is often several hundred times that of high-speed steel. In general, best results are obtained with light cuts and high speeds on cast iron and on nonferrous metals. They are, however, being used successfully on steel in many places.

Tools of this class are known by various trade names such as Carboloy, Firthite, and Vascaloy-Ramet, which includes tantalum as well as tungsten. These materials are used as tips brazed to a steel shank, which should be heavy for stiffness and to avoid vibration which tends to crumble the cutting edge. These tools require special care in grinding, as is illustrated on later pages. It is frequently economical to use carbide tools in gang setups for the larger diameter work which can then be machined at the same speed as for the high-speed tools used on the smaller diameters.

The following tool angles are suggested:

Material	Front Relief in Degrees	Side Relief, in Degrees	Side Rake Angle, in Degrees	Nose Radius, in Inches
Cast iron	6	4	12	3/8 to 1 1/4
Soft steel	6	6	14	3/8 to 1 1/4
Medium steel	6	6	14	3/8 to 1 1/4
Hard steel	4	4	14	3/8 to 1 1/4
Nonferrous	6	6	Negative	

For planer tools, 7 to 14 degrees side or rake angle and 5 degrees relief are suggested for roughing cast iron. Some finishing tools have no side rake angle or back rake. They sometimes have 3 degrees negative rake.

Feeds and Speeds

John C. Coonley, tool superintendent, and J. H. Howieson, timestudy manager, of the Walworth Company, recommend the feeds and speeds in Table 18 for carbide tools on various kinds of work.

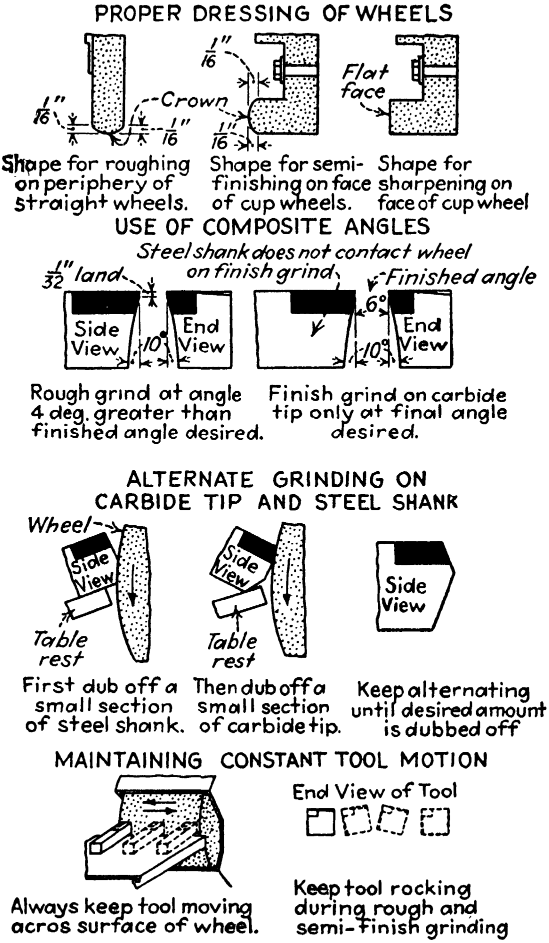

PROPER DRESSING OF WHEELS
1/16"
1/16"
Crown
1/16"
1/16"
1/16"
Flat face
Shape for roughing on periphery of straight wheels.
Shape for semi-finishing on face of cup wheels.
Shape for sharpening on face of cup wheel
USE OF COMPOSITE ANGLES
Steel shank does not contact wheel on finish grind
1/32" land
Finished angle
Side View
10°
End View
6°
10°
End View
Rough grind at angle 4 deg. greater than finished angle desired.
Finish grind on carbide tip only at final angle desired.
ALTERNATE GRINDING ON CARBIDE TIP AND STEEL SHANK
Wheel
Side View
Table rest
Side View
Table rest
Side View
First dub off a small section of steel shank.
Then dub off a small section of carbide tip.
Keep alternating until desired amount is dubbed off
MAINTAINING CONSTANT TOOL MOTION
End View of Tool
Always keep tool moving acros surface of wheel.
Keep tool rocking during rough and semi-finish grinding

FIG. 26.—Grinding Carbide Tools

Grinding Carbide Tools

Carbide tools can be ground much faster by the method shown above than was formerly thought possible. It was suggested by N. N. Shepherd of the Carboloy Company.

Dress the wheel with a crown of $\frac{1}{16}$ inch as in Fig. 26. All rough and semifinish dressing is done with a mechanical dresser. For finish grinding the cup wheel is dressed flat with a diamond impregnated carbide dresser.

The main points to remember, for rapid grinding, are to use the double or composite angle, to alternate grinding between the carbide tip and the steel shank, to keep the tool in motion, to rough grind on straight wheels, and to exert only moderate pressure while roughing and light pressure in semifinishing and sharpening. The illustrations which follow explain each operation. The finished ground angle shown is 6 degrees, and the angle for roughing is 10 degrees. These angles may vary by about 2 degrees for heavy-duty tools and from 4 to 5 degrees for light duty.

TABLE 18.—FEEDS AND SPEEDS OF CARBIDE TOOLS ON VARIOUS MATERIALS

Operation	Surface Speed, in Feet per Minute	Feed, in Inches	Depth of Cut in Inches	Pieces per Tool Grind
Machining 500 Brinell 18 chrome 0.90 carbon steel	350	0.002	0.008 (2 cuts)	100
Facing carbon molybdenum steel castings......	100	0.032	$\frac{1}{8}$ to $\frac{1}{4}$	25
Machining monel-metal valve yokes............	150	0.012	$\frac{3}{32}$	60
Facing and turning bronze gate-valve wedges......	700	0.004	$\frac{1}{32}$	1,000
Turning and facing stainless gate-valve wedges..	80	0.012	$\frac{3}{16}$	50

The use of correct grinding wheels is also an important factor. There are available today wheels which are entirely satisfactory for rapid grinding without injury to the carbide tip. The specifications follow:

SILICON CARBIDE WHEELS FOR GRINDING CARBIDES

(*A*) Straight Wheels

(For *roughing only*. Wheels should not be used after wearing down to 6 inches diameter owing to excessive concave surface ground on tools when wheels wear down to smaller diameters)

Carborundum.............	60R-WGG................	(straight)
Norton....................	3760I7..................	(straight)

(*B*) Cup Wheels

	ROUGH	FINISH
Carborundum..................	60R—WGG	120S—WHG (or 100S)
Norton.......................	3760I7	37120 H plus 7 (or 37100)

Under no circumstances should wheels other than special silicon carbide wheels be used for grinding carbide, and these wheels should be of the soft grades recommended. Correct wheel speed is about 5,000 surface feet per minute.

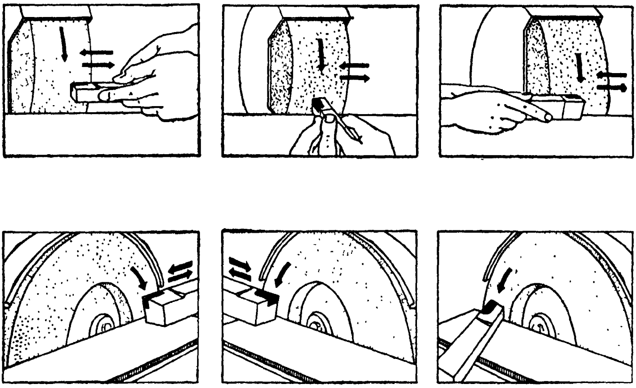


FIG. 27.—Details of Grinding Operations

Detailed grinding operations are shown in Fig. 27 and are described below.

1. **Rough Top Face.**—Rough hollow-grind top face of tool on periphery of straight wheel (with crowned surface). Hold tool in hands (not against table). Leave about $\frac{1}{32}$ inch land at the cutting edge of the tool. Use 60-grit, soft, silicon carbide wheel. This free-hand grinding is done only when one or two tools are to be ground. When a quantity of tools with the same top side rake are to be ground, set the table at the proper angle to save time and maintain the correct top rake.

2. **Rough Front Clearance.**—Set table rest at 10 degrees (4 degrees greater than finished angle desired), and rough-grind front clearance, leaving about $\frac{1}{32}$ inch land at cutting edge. Hold tool against table rest. Use same wheel as in (1). Angle at which table rest is set will vary with the diameter of the wheel. However, 10 degrees should be angle on tool.

3. **Rough Side Clearance.**—Rough-grind side clearance. Use same wheel and same angle of table rest as in (2).

4. **Semifinish Top Face.**—Using face of cup wheel (prepared with $\frac{1}{32}$ to $\frac{1}{16}$ inch crowned surface), and with table rest set at finished angle desired, semifinish-grind top face of tool. Use 100- or 120-grit, soft silicon carbide wheel.

5. **Semifinish Side Clearance.**—Set table rest at 6 degrees (finished angle desired). Reverse wheel direction and on left-hand face of wheel semifinish-grind side clearance. Note that wheel rotation is always *from* carbide tip *to* steel shank. Use same wheel as in (4).

6. **Semifinish Front Clearance.**—Semifinish-grind front clearance, also radius on nose of tool. Use same wheel as in (5).

7. **Sharpen Top Face.**—Set table rest for correct top side rake. On same wheel as in (6), dress a flat surface on the face, using diamond-impregnated carbide dresser, and use wheel dressed in this way for the following operations which are required to sharpen the tool, (8), (9), (10). Reverse direction of wheel and on right-hand face of wheel, sharpen top face of tool.

8. **Sharpen Side Clearance.**—Set table rest on 6 degrees (finished angle). Reverse wheel, and on left-hand face of wheel finish-grind side clearance. Use wheel dressed the same as in (7). Examine for finish by holding the tool so that light reflects across the surface of the tip.

9. **Sharpen Front Clearance.**—Finish-grind front clearance, using wheel dressed the same as in (8) and table rest at same angle.

10. **Sharpen Radius.**—Finish-grind radius on nose of tool. Use same wheel as in (9) and table rest at same angle.

When it is necessary to grind the top face, this is always done before grinding on the side or front clearances. This is particularly important when finish-grinding, if the best possible cutting edge is desired. When grinding on the top face, the movement across the face of the cup wheel is limited to a small area. Because of this, a slight recess is formed in the wheel as the tool is being ground. The corner of this recess rubs the front and nose of the tool and tends to dull those surfaces. By grinding the front and side clearance *last*, this difficulty is avoided.

SHARPENING ON DIAMOND WHEELS AND LAPPING DISCS

The procedure for finish-grinding, or sharpening, carbide tools on diamond wheels or lapping discs is the same as operations shown in Fig. 26. Use less pressure of the tool against the wheel and, when employing diamond wheels be careful to use the entire surface of the wheel, keeping the tool slowly in motion across the wheel. When the diamond wheels become loaded, apply pumice stone lightly against the revolving wheel. Frequently an ordinary paint brush saturated in kerosene will be sufficient to open up the wheel. For lubricating the wheel, use kerosene applied at the rate of about 40 drops per minute.

When using diamond-charged lapping discs follow the same sharpening procedure as described for diamond wheels. Occasionally add a small amount of No. 4 diamond dust immersed in olive oil to the surface of the tool in contact with the disc.

STAINLESS STEEL

High-chromium steels tend to gall or seize under pressure, and chips weld to the tool, producing a built-up edge which heats the tool and interferes with the finish. Chromium-nickel stainless steels also work harden rapidly from the tool action, particularly in milling and drilling. Speed should be reduced, the feed increased, and the tool kept cutting, as idling glazes the work.

Straight chromium steels can be turned at 50 to 75 feet per minute and chrome nickel at 30 to 45 feet. These speeds can be doubled in the free machining grades. A steep top rake of 20 to 22 degrees helps prevent galling, especially if the top of the tool is stoned. High-sulphur-base oil (1 pound of sulphur to the gallon) is a good coolant. Tool upkeep is two or three times that for mild steel. Yet stainless is machined in automatics if hardness is between 200 and 240 Brinell.

Drill at about half speed for mild steel, and keep drill feeding. Cast iron makes a good backing for steel being drilled. Turpentine added to the sulphur-base oil helps in drilling.

Threading is similar to soft brass for both chasing tools and taps. Tap at about 15 feet surface speed for straight chromium and 9 to 10 feet for chrome nickel. Increase speed 50 per cent for free machining grades. A paste of white lead and high-sulphur oil helps in threading. High-speed taps and dies, collapsible where possible, are best.

SIZES OF CENTERS IN ARBORS

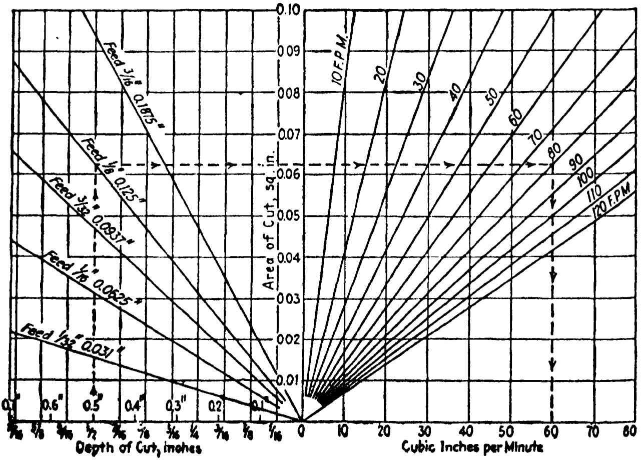
The accompanying table gives a few of the sizes of center drills and countersinks used by the Remington Arms Co., Ilion, N. Y., on its mandrels.

TABLE 19.—CENTER DRILLS AND COUNTERSINKS

A Diam. of Mandrel	*B* Largest Diam. of Center	*C* Size of Drill	*D* Depth of Hole
0.25	0.12	0.052 (#55)	0.15
0.50	0.25	0.102 (#38)	0.30
0.75	0.38	0.152 (#24)	0.45
1.00	0.50	0.199 (#8)	0.60
1.25	0.53	0.213 (#3)	0.64
1.50	0.56	0.228 (#1)	0.68
1.75	0.59	0.238 (#B)	0.73
2.00	0.62	0.250 (#E)	0.77
2.50	0.69	0.272 (#I)	0.85
3.00	0.75	0.302 (#N)	0.94
3.50	0.82	0.323 (#P)	1.00
4.00	0.88	0.348 (#S)	1.10

CHART OF METAL REMOVED AT VARIOUS CUTS, FEEDS, AND SPEEDS

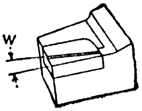
The chart enables rapid estimating of metal removed under varying conditions. To use the chart, start with the depth of cut



at bottom of left side. With a $\frac{1}{2}$-inch cut and $\frac{1}{8}$-inch width feed at 80 feet per minute, start at $\frac{1}{2}$-inch feed, go up the $\frac{1}{8}$-inch feed line, across to 80-feet cutting speed, which shows that 60 cubic inches per minute is being removed. Depth of cut is also shown in decimals of an inch, and the figures in the center show the area of the cut in square inches.

CHIP BREAKERS

Chip breakers are very useful in high speed turning with carbide tools. The Carboloy Company make the following suggestions: Fit each chip breaker to the job. Ground-in, step type shown in diagram is usually best. The table below shows recommended width *W*. A breaker depth of 0.020 inch is generally satisfactory.



Depth Cut, in Inches	Feed, in Inches per Rev.				
	.008–.012	.013–.017	.018–.022	.023–.027	.028–.032
$\frac{1}{64}$–$\frac{3}{64}$	$\frac{1}{16}$	$\frac{5}{64}$	$\frac{3}{32}$	$\frac{7}{64}$	$\frac{1}{8}$
$\frac{1}{16}$–$\frac{1}{4}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{11}{64}$	$\frac{3}{16}$
$\frac{5}{16}$–$\frac{1}{2}$	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{13}{64}$	$\frac{7}{32}$
$\frac{9}{16}$–$\frac{3}{4}$	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{7}{32}$	$\frac{15}{64}$	$\frac{1}{4}$

TURNING TAPERS BETWEEN CENTERS

Tapers can be cut between lathe centers either by setting over the tail center or by using a taper attachment. In either case the angle must be one-half the difference in diameters between the two ends of the taper, if it extended the whole length of the piece. To turn a piece 20 inches long, 5 inches at one end, and 3 inches at the other, as Fig. 28, the tail stock must be set over 1 inch, this being one-half of the difference between 5 and 3.

If the taper extends only half the length of the piece, with the same difference in diameter, the tail stock must be set over twice as far, or 2 inches, for the true taper is now from 3 inches at the small end and 7 inches at the large end. The difference is 4 inches, making it necessary to set the tail stock over 2 inches (see Fig. 29).

A third case is shown in Fig. 30, where the taper is not at either end. With the same difference between large and small diameters, the taper is again twice as great as in Fig. 29, the dotted lines showing the taper extended the whole length of the piece. This would be 1 inch at the small end and 9 inches at the large end, a difference of 8 inches, requiring a setover of 4 inches.

Extreme tapers of this kind are not easy to turn by setting over the tail stock. The point of the cutting tool must be set at the same height as the lathe centers. Figures 31, 32, and 33 show work set over in lathe.

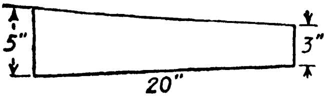


FIG. 28.

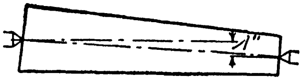


FIG. 31.

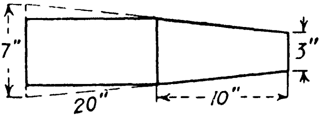


FIG. 29.

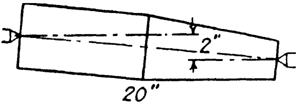


FIG. 32.

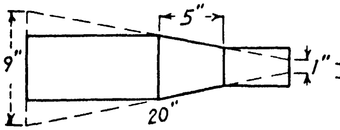


FIG. 30.
Location of Tapers

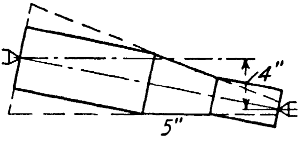


FIG. 33.
Setover in Lathe

FIGS. 28 to 33.—Tapers and Setover in Lathe.

SPINNING

Spinning is an old process of forming sheet metal over a wood or metal form as both are revolved in a lathe. Skill is required to control the flow of metal as desired. Speeds vary from 500 to 2,000 revolutions per minute, and some lathes are powered with a 5 horsepower direct-current motor. Spinning lathe spindles are made to stand an end pressure of 2,000 pounds.

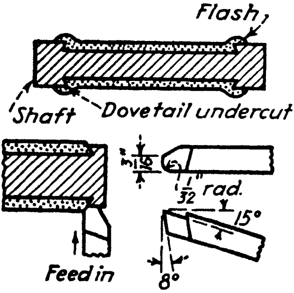
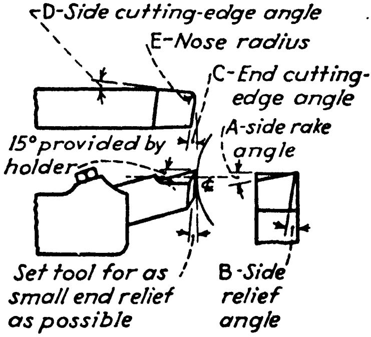


FIG. 34.

TURNING SPRAYED METALS

Many surfaces built up with sprayed metal require turning to size. Unless tools are sharp and both speeds and feeds right, the sprayed coating may be torn off. Sprayed steels sometimes form a hard ring near the ends of the undercut section. These hard rings should be turned first with a flat-nosed tool, fed straight in (see Fig. 34). Tungsten carbide tools are useful in this work.

TABLE 20.—HIGH-SPEED TOOLS, SPEEDS AND FEEDS FOR MACHINING SPRAYED METALS



Tool No.	Angles, Degree				Nose Rad. *E* Inches
	A	*B*	*C*	*D*	
1	0	10	10	3-5	0.030
2	10	10	10	3-5	0.030
3	15	10	10	3-5	0.040

Metal	Tool No.	Surface Speed, Ft. per Min.	Feed, In. per Rev.
Aluminum*	3	150 to 200	0.003 to 0.005
Sprababbitt	3	150 to 250	0.005 to 0.007
Sprabrass Y†	2	100 to 125	0.003 to 0 005
Sprabronze A	1	100 to 125	0.003 to 0.005
Sprabronze C†	3	100 to 125	0.003 to 0.005
Sprabronze M	1	100 to 125	0.003 to 0.005
Sprabronze P	1	100 to 125	0.003 to 0.005
Sprabronze T	1	100 to 125	0.003 to 0.005
Monel	3	100 to 125	0.003 to 0.005
Nickel	3	100 to 125	0.003 to 0.005
Sprairon A‡	3	75 to 100	0.003 to 0.005
Copper*	3	100 to 125	0.003 to 0.005
Lead	3	150 to 250	0.005 to 0.010
Metcoloy No. 1	3	100 to 125	0.003 to 0.005
Metcoloy No. 2		Grind	
Sprasteel 10‡	3	75 to 100	0.003 to 0.005
Sprasteel 25‡	2	50 to 75	0.003 to 0.005
Sprasteel 40‡	2	50 to 75	0.003 to 0.005
Sprasteel 80		Grind	
Sprasteel 120		Grind	
Tin	3	150 to 250	0.005 to 0.007
Zinc	3	150 to 250	0.005 to 0.007

NOTE: Do not use this treatment on Metcoloy No. 1, nickel, monel, Sprabronzes A, M and P, since it will result in a poorer rather than better machine finish.

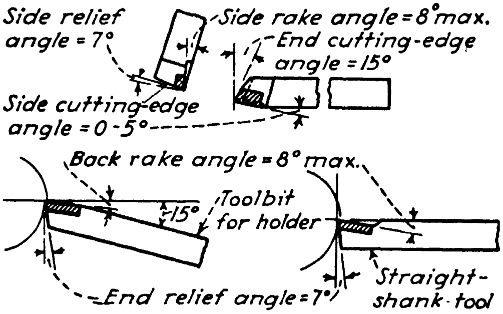
* The same treatment applied to copper and aluminum will give a slight improvement to the machine finish.

† To improve the machine finish on Sprabronze C and Sprabrass Y, apply a liberal coat of a mixture of one part cylinder oil plus one part kerosene to the sprayed metal with a brush, and allow to stand for 20 to 30 min. before machining.

They give better finishes than high-speed steel. The tool may be set on center for roughing and raised slightly for finishing. The tool can be raised more when turning sprayed monel, nickel, or bronze.

As cuts on sprayed metal are seldom over 0.020 in. deep the side cutting angle is of little importance. Tool shapes for both high-speed steel and carbide tools are shown in Tables 20 and 21.

TABLE 21.—RECOMMENDED SPEEDS AND FEEDS FOR TUNGSTEN-CARBIDE TOOLS


Side relief angle = 7°
Side rake angle = 8° max.
End cutting-edge angle = 15°
Side cutting-edge angle = 0-5°
Back rake angle = 8° max.
15°
Toolbit for holder
End relief angle = 7°
Straight-shank tool

Metal	Surface Speed, Ft. per Min.		Feed, In. per Rev.	
	Roughing	Finishing	Roughing	Finishing
Sprabrass Y	250 to 300	300 to 350	0.006	0.002
Sprabronze C	250 to 300	300 to 350	0.006	0.002
Sprabronze M	250 to 300	300 to 350	0.006	0.003
Sprabronze P	250 to 300	300 to 350	0.006	0.003
Sprabronze T	250 to 300	300 to 350	0.006	0.003
Copper	250 to 300	300 to 350	0.006	0.003
Sprairon	75 to 100	100 to 125	0.006	0.003
Metcoloy No. 1	100 to 125	125 to 175	0.006	0.003
Metcoloy No. 2	30 to 40	30 to 40	0.004	0.003
Monel	200 to 250	250 to 300	0.004	0.002
Nickel	200 to 250	250 to 300	0.004	0.002
Sprasteel 10	75 to 100	75 to 100	0.006	0.003
Sprasteel 25	50 to 75	50 to 75	0.004	0.003
Sprasteel 40	30 to 40	30 to 40	0.004	0.003
Sprasteel 80	30 to 40	30 to 40	0.004	0.003
Sprasteel 120	30 to 40	30 to 40	0.004	0.003
Sprasteel 52E	30 to 40	30 to 40	0.004	0.003

SECTION X

MILLING-MACHINE FEEDS AND SPEEDS

War demands for increased production brought drastic changes in milling machine and cutter practice. Cutter designs have been changed and both speeds and feeds increased far beyond previous rates. In some cases on light cuts aluminum and magnesium are being milled at 20,000 surface feet per minute and steel at 1,200 feet, but these speeds do not represent average practice. Much depends on the condition of the spindle bearings and their support, on the strength of the machine, on the rigidity of the work and fixture which holds it, on the cutters themselves, and on the power available at the spindle. It is essential that there be no vibration in the machines, that the slides guide the work without shake, and that there be no backlash in any of the feed screws or other feeding mechanisms.

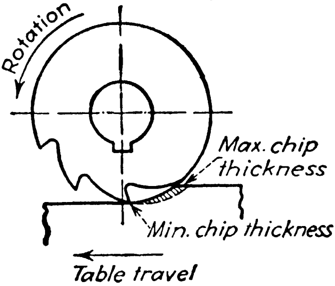


FIG. 1.—Feeding against Cut "Up" or "Out" milling

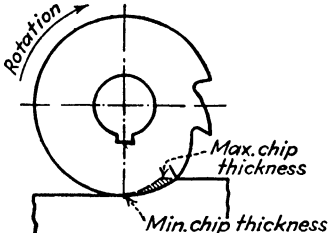


FIG. 2.—"Climb" Cutting "Down" or "In" Milling

Compensating feed nuts now eliminate backlash in feed screws and make *climb* or *down* feed possible, in mechanically operated feeds. This has advantages in most cases where milling is done with the periphery or outside of milling cutters used for flat surfaces on horizontal spindle machines, sometimes known as slab milling. This term also applies to narrow faced cutters used in cutting slots of keyways. It is necessary to avoid confusion between this type of milling and the use of face- or end-mills for surfacing, or for cutting keyways, particularly in view of the trend toward using milling cutters with negative instead of positive rake to the teeth, for some classes of work.

Terms indicating direction of feed have not been standardized. "Conventional" and "climb" milling are likely to give way to "up" and "down" milling or to "in" and "out" milling. For slab milling "up" and "down" are quite descriptive but for both slab and face milling "in" and "out" seem better, and are advocated by Prof. O. W. Boston. See Figs. 1 and 2.

Neither the high speeds mentioned nor the new types of cutters mean that all former practice has been abandoned. Because of existing low-powered milling machines, of older types of cutters, and of the small quantities involved in many cases, much of our former practice as to feeds and speeds will be continued in many shops. But the newer methods should be carefully studied and understood so that they may be applied whenever it is possible to do so to advantage, as they have shown greater productive possibilities than ever existed before.

The essential requirements of high-speed milling are: cutters that will stand impact with the work at high peripheral speed; positive feed which gives a chip of sufficient thickness to each tooth as it strikes the work; and power enough to revolve the cutter at a speed which secures the most economical results when cutter life and other factors are considered. It is assumed that the work is substantial enough to stand the most economical feed, that it is rigidly held in its fixture, and that the machine has the necessary strength and power for the work.

Assuming that sufficient power is available at the spindle, the feed per minute can be easily calculated if one knows the speed at which the cutter can safely be run in any given material, the economical chip thickness per tooth, and the number of teeth in the cutter. A single tooth or fly cutter, running 3,000 r.p.m. with a chip load of 0.005 inch, would give a feed of 3,000 × 0.005 or 15 inches per minute. With two teeth, the feed rate would be 30 inches per minute and would presumably take twice the power, so that both on account of the power required and on account of the cost of cutters, there is a tendency to use as few teeth as is possible or practicable. With carbide cutting edges this is an appreciable saving. Carbide tipped cutters, brazed or welded to cast or low grade steel centers or bodies, are proving both very economical and very satisfactory. Arthur A. Schwartz, chief tool research engineer for Bell Aircraft Corporation, who has pioneered much development along this line, favors meehanite for the cutter body, feeling that it helps absorb vibration more than some steel. He has done some remarkable milling with single-tooth helical cutters on wide surfaces and advocates as few teeth as practicable for almost all classes of work. Milling cutters with from four to six teeth are common even in diameters up to 6 and 8 inches, and for very high speeds on soft metals one and two teeth are often used. Another advantage of cutters with few teeth is the large chip space between them.

Flywheels on milling machine spindles are highly desirable, especially where the chip load per tooth is heavy. They prevent any slowing down of the cutter while it is in contact with the work. or any acceleration on leaving the cut. They also help lengthen the cutter life and make a more smoothly running machine. Flywheels should be as near the milling cutter as possible. In some special cases the cutter body has been fastened to the flywheel. Some advocate a flywheel at each end of the spindle to avoid any tendency of the spindle itself to twist under heavy load. The flywheel should be heavy enough to ensure steady running of the cutter at all times.

NOMENCLATURE OF MILLING CUTTER TEETH

To avoid misunderstandings regarding the meaning of terms used in discussing milling cutter teeth and their angles, the illustrations show what is being considered by the Committees of the American Society of Mechanical Engineers, of which Prof. O. W. Boston is chairman. These terms have been suggested for plain or slab cutters, for side-milling cutters, and for face-milling cutters. An understanding of them will avoid confusion in describing or discussing cutting and other angles. The values given are suggested as being suitable for high-speed cutters. See Figs. 3, 4 and 5.

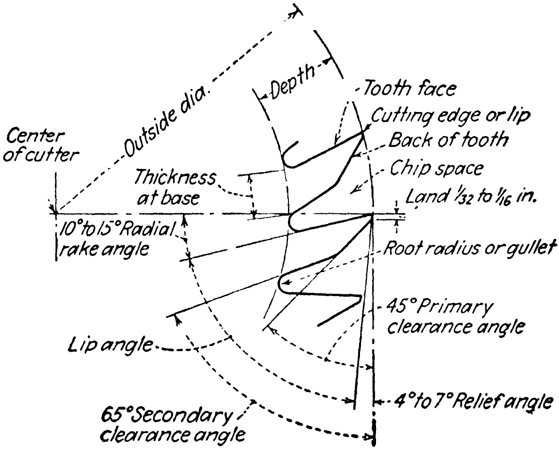


FIG. 3.—Plain Milling Cutter Teeth. Suggestions for High-Speed Steel Cutters for General Use.

FEEDS AND SPEEDS

Developments in milling practice include the use of milling cutters with carbide tips brazed to cast iron or steel bodies, of those with blades of solid carbide held in the body by wedges of different sorts, and in some cases of small cutters where the whole cutter body is formed of carbide and ground to the desired cutting angles and clearances. Cutters with negative rake are also being used successfully in milling steel, and much higher cutting speeds have been adopted in many cases. Negative rake cutters usually produce a smoother finish on the work because of the burnishing action, but in most cases they take more power. Some contend that the excess of power they require over positive rake cutters decreases as the speed is increased and that at high speeds less power is needed than with positive rake. This is attributed to the heating and softening of the metal at the higher speeds, but this is not the universal opinion.

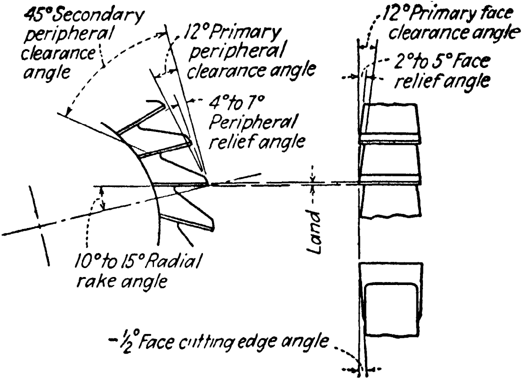
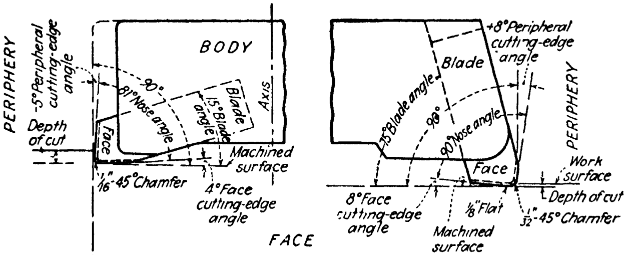

45° Secondary peripheral clearance angle
12° Primary peripheral clearance angle
4° to 7° Peripheral relief angle
10° to 15° Radial rake angle
Land
12° Primary face clearance angle
2° to 5° Face relief angle
-½° Face cutting edge angle

FIG. 4.—Side-Milling Cutter. Suggestions for High-Speed Steel Cutters for General Use.



Blade placed in holder to permit radial adjustment required by peripheral wear as in deep cuts

Blade placed in holder to permit axial adjustment required by face wear as in shallow cuts

FIG. 5.—Face-Milling Cutter. High-Speed Steel Cutters for General Use.

The best speeds and feeds to be used still depend on the material being cut, the power of the machine, the kind of cutter, the ability of the work to withstand the pressure of the cutter, and the ability of the fixture to hold the work against deflection or loosening. Whether carbide or high speed steel cutters are used, probably the most important factor is the thickness of the chip taken by each tooth. Regardless of the material in the cutter, a light, scraping cut is injurious to the cutter. Each tooth should have a definite and substantial chip to secure the best results. The tendency toward coarse-toothed cutters has increased in the case of carbide cutters, one fairly common practice being to make the number of teeth two more than the diameter of the cutter in inches. In many cases where the speed can be high enough to warrant it, especially on aluminum and the softer metals, single tooth or fly cutters are used very successfully. On some light cuts in aluminum, speeds of 20,000 surface feet per minute have been used.

Since cutter wear depends on the number of contacts with the work, it is evident that the more metal to be safely removed by each tooth the longer the cutter life. But the fact that the heavier chip requires more power may limit the number of teeth to be used. It must also be remembered that the chip taken by a milling cutter differs materially from that of a lathe tool which is of uniform section. With the milling cutter, the chip varies from start to finish. This variation depends on the kind of cutter and the method of feeding it to the work. With the slab milling cutter using the *up* or conventional feed the chip begins at zero thickness and ends with the maximum. With the climb or *down* feed this is reversed. In face milling, which is being used wherever it can be applied in most cases, the chip thickness varies with the relation between the diameter of the cutter and the width of the work. It also varies with the location of the entering edge of the work with relation to the center of the cutter.

Tests at the Brown & Sharpe Manufacturing Company and elsewhere show that coarse tooth milling cutters require less power to remove a given amount of metal. They also leave a better finish. Milling efficiency is increased by heavy feeds per tooth. Coarse teeth also have less tendency to chatter. Rake angles affect the power needed. For carbon and high-speed cutters positive rakes are in general use, but for carbide cutters on steel the negative rake angles give much longer cutter life and a smoother finish. The positive rake angles vary, but rarely are over 10 and 15 degrees. High-speed cutters in which the face of the tooth is curved and which have up to 20 degrees positive angle show small power consumption. This is attributed to the curved face helping to curl the chip, and so taking less power.

Much research has been devoted to the action of milling cutters on various metals, principally steel, cast iron, and aluminum. The large makers of milling machines have made public the results of their work through the Mechanical Engineering Committee of the A.S.M.E., which has worked in conjunction with the Research division of W.P.B. Much of this and other data has been issued to those engaged in making war materials to speed production of much needed equipment. Makers of various cutting materials, especially of the carbide types, have also supplied valuable data which have helped the war effort and which can be of great value to all shops engaged in peacetime work later.

Chip formation is being studied by those responsible for economical milling practice. The deformation of the chip as it leaves the tool adds heat which indicates power consumption. Fortunately most of this heat goes into the chip instead of in the cutter and the work. Deformed or closely rolled chips turn a dark blue just as in drawing the temper of a tool. Particles become red hot, as from a grinding wheel. Chips which are not so deformed remain at a straw color or are hardly colored at all. These chips are not tightly curled but remain almost flat and indicate that less power is required to remove them. Chips of this type evidently indicate greater efficiency in removing metal.

RAKE AND HELIX ANGLES OF MILLING CUTTERS

"Rake" is the angle between the cutting edge and the work. With the cutting edge at right angles to the surface being cut, the tool has a "zero" rake. Where the cutting edge is ahead of the axis of the cutter, and gives a shearing cut, the rake is positive. If this is reversed, with the cutting edge behind the axis of the cutter, the rake is negative.

Similarly, the helix angle of the cutting teeth is zero, positive, or negative, depending on their relation to the cutting edge. As can be seen, *these terms apply only to face or end mills.* On milling cutters of the slab or peripheral type, the helix angle is merely right-hand or left-hand.

When both radial and axial rake angles are used, the net results may not be what they seem to be. This is shown clearly by M. Kronenberg on the following pages, which should be studied carefully. Combinations of axial and radial rakes should only be made after understanding how they affect each other. An unusual combination which gives good results is shown in Fig. 15.

TRUE RAKE OF TEETH OF FACE MILLS

The increasing use of face mills with negative rake cutting edges makes it necessary to consider the *true* rake in determining the performance of the cutter. This is explained by M. Kronenberg, Eng. D., of the Research Department of the Cincinnati Milling Machine Co., as follows:

"A face mill with its teeth set at a 10 degree negative radial rake angle may in effect be cutting with a positive rake.

"When the axial and radial rakes are both positive or both negative, the true rake may be greater than either one of them.

"The true rake of a cutter can be varied many degrees without changing either the axial or radial rake."

These strange statements are explained by the fact that the "true" rake is an angle which is the resultant of three others—the radial rake, the axial rake, and the corner angle. To describe a cutter by means of only the first two of these components is insufficient. See Figs. 6 to 9.

True rake is measured at right angles to the projection of the cutting edge on the reference plane. In general it serves as a useful index to cutter performance since it affects not only the tool life but also the finish quality of the work, the power consumption, and the deflection of the machine. In extreme cases where the cutting edge is greatly inclined to the reference plane, its angle of inclination must also be considered in estimating cutter performance.

Since it is therefore necessary for the practical designer and user of cutters to think in terms of true rake, it is desirable to have some easy means for determining what this significant angle will be for a given combination of its three components.

The alignment chart on Fig. 10 permits the reading of the value and variation of any one of the angles if the three other angles are given or varied. It is necessary only to lay a straightedge across the chart connecting the values for the given angles.

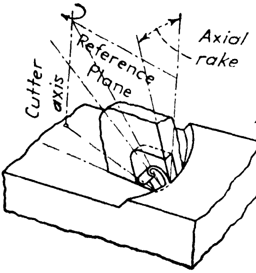


FIG. 6.—Axial Rake.

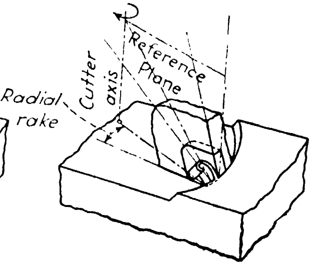


FIG. 7.—Radial Rake.

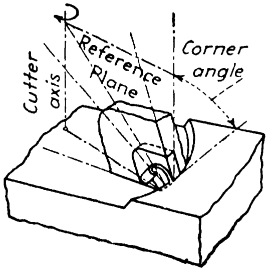


FIG. 8.—Corner Angle.

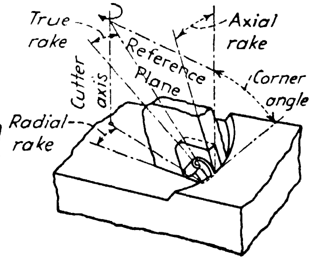


FIG. 9.—True Rake.

If the true rake is to be determined, the given value of the radial rake should be connected with the value of the axial rake. The true rake can then be read for any value of the corner angle at the intersection of the ruler's edge with the vertical line.

If, on the other hand, a certain value for the true rake is desired and the corner angle and radial rake are given, the required axial rake can be determined by laying a straightedge from the radial rake value through the proper intersection point between the corner angle and the desired true rake value. When the other end of the straightedge crosses the axial rake scale, the proper axial rake value can be read directly.

By experimenting with the alignment chart, choosing various combinations of values and considering the situations caused by multiple corner angles or rounded tool noses, many important facts can be learned. Among them are the following significant results.

1. Grinding a different corner angle on the tooth of a cutter changes the magnitude of the true rake and affects cutter performance.

2. A chamfered cutting tooth has two different true rake angles, and three where there are two chamfers.

3. On a tool with a rounded nose, the true rake varies along the curved portion because the corner angle varies from point to point of the cutting edge.

4. The true rake will always be positive if the axial rake and the radial rake are both positive; it will always be negative if these rakes are both negative. The true rake, however, can be either positive or negative if the axial and radial rake have opposite signs.

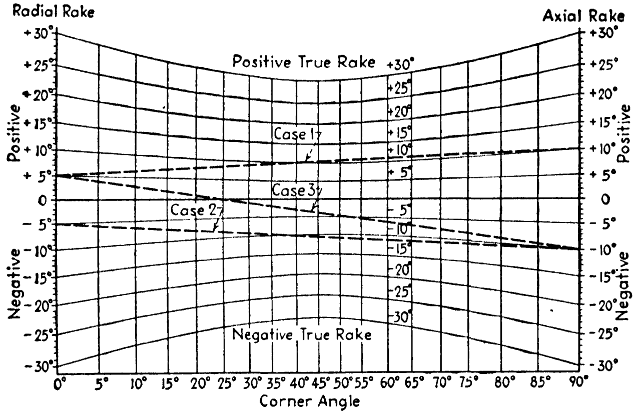


FIG. 10.—Resultant Angle Due to Continued Rake and Helix Angles.

5. Changing the radial rake will appreciably alter the true rake if the corner angle is small, but will have little effect if the corner angle is large. Conversely, changing the axial rake will have little influence on the true rake if the corner angle is small, but an appreciable effect if the angle is large.

The alignment chart and conclusions hold also for lathe tools, if the term "axial rake" is replaced by "back rake" and the term "radial rake" by "side rake."

When collecting production data it will often be useful to plot tool life vs. true rake; this will not necessarily give a straight line, because of the influence of other factors such as friction. Such plotting will allow judging and improving results which might be difficult to comprehend.

Examples

1. Given: a radial rake of ± 5 degrees and an axial rake of ± 10 degrees. Required: the corner angle which will give a true rake of ± 10 degrees.

Solution: The point of intersection between the straight edge (yellow line) and the ± 10 degrees rake line falls between the 35-degree and 40-degree corner angle vertical line (arrow), indicating about 37 degrees for the required corner angle.

2. Given: a radial rake of −5 degrees, an axial rake of −10 degrees, and a corner angle of 20 degrees.

Required: the true rake.

Solution: The point of intersection between the ruler's edge and the 20-degree corner angle line falls between the −5-degree and −10-degree rake lines (arrow) indicating that the true rake is approximately −8 degrees.

3. Given: a radial rake +5 degrees and an axial rate of −10 degrees.

Required: the range of corner angles which will result in negative rakes.

Solution: The ruler's edge dips below the zero rake line at the 20-degree corner angle line (arrow), indicating that the true rake will be negative for any corner angle greater than 26 degrees.

Varying Chip Thickness

Chip thickness varies widely with the relation between the cutter and the work, especially in face milling. In slab milling the chip varies from zero to the feed per tooth, whether the feed is *up* or *down*. In face milling the variation depends on the relative width of the work and the diameter of the cutter. Both cases are shown in Fig. 11.

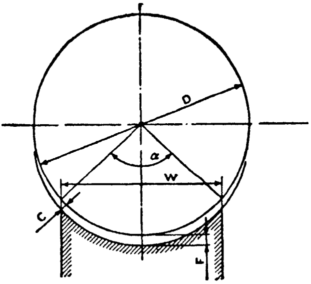


FIG. 11.—*D*, Cutter Diameter; *W*, Width of Work; *F*, Feed per Tooth.

$\frac{W}{D}$ = ratio of width of work to cutter diameter

α = included angle of cut

C = normal thickness of chip at edge of work (per cent of feed per tooth)

$\frac{W}{D}$	α	C, %	$\frac{W}{D}$	α	C, %	$\frac{W}{D}$	α	C, %
1.00	180°	0	0.70	89°	71	0.35	41°	94
0.98	157°	20	0.65	81°	76	0.30	35°	95
0.95	142°	32	0.60	74°	80	0.25	29°	97
0.90	128°	44	0.55	67°	83	0.20	23°	98
0.85	116°	53	0.50	60°	87	0.15	17°	99
0.80	106°	60	0.45	54°	89	0.10	11½°	99
0.75	97°	66	0.40	47°	92			

With the work the same width as the diameter of the cutter the chip is of zero thickness at each end and maximum thickness in the center. The thickness at the edge of work of various widths as compared with different cutters is shown in the diagram and table prepared by L. B. Mayo of the Brown & Sharpe Mfg. Co. It is usually advisable to have the cutter diameter at least one-third

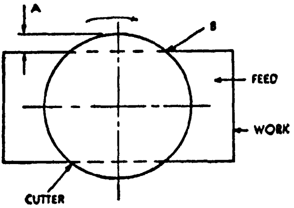


FIG. 12.

more than the width of the work. To mill work 3 inches wide the cutter should be at least 4 inches in diameter. If, as sometimes happens, a burr forms where the cutter enters the work as at *B* in Fig. 12, this may be corrected by moving the work so as to increase the overhang *A* on the entering side.

The location of the edge of the work with regard to the center of the cutter also affects the angle of contact between the cutting blade and the work. When the contacting edge is below the center of the cutter the first impact on the tooth is behind the cutting point of the tool. In milling across a round bar the angle of contact is constantly changing from the first contact until the bar is milled all the way across.

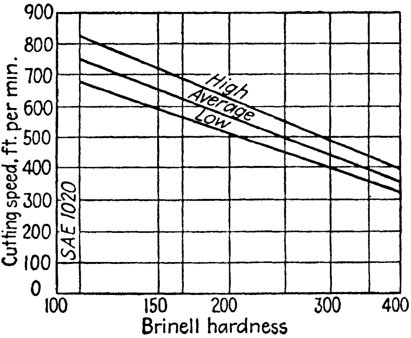


FIG. 13.—Relation between Hardness and Speed.

Suggested Milling Speeds for Carbide Cutters

The suggested milling speeds which follow are by the courtesy of the Cincinnati Milling Machine Company and bear the date of June 21, 1944. They are based on conditions found in their own shop practice and may be revised as experience dictates.

Brinell Hardness	Cutting Speed, in Feet per Minute		Typical Material
	Average	Limits, 10 Per Cent of Average	
110	750	675 to 825	SAE 1020
165	630	567 to 693	SAE 1112
180	600	540 to 660	Annealed
200	570	513 to 627	Alloy
220	540	486 to 594	Steels
250	500	450 to 550	
300	450	405 to 495	Hardened
325	425	382 to 468	Alloy
350	400	360 to 440	Steels
400	360	324 to 396	

NOTE.—For steel castings and forgings where hard inclusions may be encountered, the above recommended cutting speeds should be reduced about one-third.

General Rules for Speed Selection

Always find hardness of steel first. Too high a speed on hard steel may ruin the cutter instantly.

Start a new job with the average speed recommended. If the cutter sparks prematurely, reduce the speed to the lower limit.

For a fine finish, use higher speed limit. For maximum cutter life, use lower speeds.

If the carbide edge begins to fail rapidly by abrasion, reduce the speed. If it begins to crater prematurely, increase the speed. The chart Fig. 13 gives a general idea of the relation between hardness and speed.

General Rules for Feed Selection

TABLE 1.—RECOMMENDED FEEDS FOR MILLING STEEL WITH CARBIDES

TYPE OF MILLING	FEED PER TOOTH, IN INCHES	
Face	0.006 to	0.012
Side or straddle	0.008	0.012
Slab	0.008	0.012
Slotting	0.006	0.010
Sawing	0.003	0.006

Maximum feed depends on power available in the machine and on the rigidity of the work and fixture. Check these to determine feed.

Select the feed. Remember that for shallow slotting cuts the maximum chip thickness may be only 10 per cent to 50 per cent of the feed per tooth. On such cuts increase the feed so as to obtain a maximum chip thickness of 0.004 to 0.008 inch.

If the carbide edge begins to fail rapidly, increase the feed per tooth.

If it begins to crater too rapidly, reduce the feed per tooth.

The cutting edge builds up less at higher speeds.

Points on Milling

1. Wear on positive rake cutters increases power consumption much faster than wear on negative rake cutters. The greater the negative angle the less the increase in wear.

2. Spindle speeds should not be a multiple of the number of teeth in the milling cutter if smooth surfaces are desired.

3. There should always be one tooth in contact in the cut unless there is a very heavy flywheel, as with single-point or fly cutters.

4. Flywheels not only help carry the cutter tooth through the work at constant speed but also prevent acceleration when the tooth leaves the cut.

5. When several cutters having the same number of teeth are mounted on a single arbor the key sets should be arranged so as to stagger the teeth. This will give smoother work and also increase the number of pieces per grind.

6. Flywheels should be placed as near the cutters as possible. They can sometimes be placed on the milling cutter arbor and near

the cutters where the work does not interfere. In some cases it is necessary to place them on the back end of the machine spindle but this might permit some distortion in the spindle.

7. Milling with carbide cutters should be done *dry* as a coolant of any kind is sure to crack the carbide.

Milling Speeds and Material Hardness

A chart covering milling speeds for a variety of materials with cutters of different kinds is shown in Fig. 14. This is by M. Martellotti, Research Engineer of the Cincinnati Milling Machine Co., and was released in August, 1944. It covers aluminum and magnesium alloys, plastics, cast iron, and steels up to 400 B. H. N. (Brinell Hardness Number). It also shows how Brinell hardness compares with tensile strength of materials; this information is useful as some specifications refer to tensile strength.

This chart gives a good general picture of milling practice in condensed form. It shows that the Brinell hardness of aluminum alloys and plastics runs to 125; of magnesium and alloys, to 80; of brass and bronzes, to from 80 to 250; of cast irons, perhaps to 300; of carbon steels and cast steels, between 125 and 200; of alloy steels from 200 to 400 and stainless steels from 150 to 250. It also shows that the tensile strength in 1,000 pounds is about half the Brinell of the same material. These are, of course, general figures.

Studying the cutting speed which can normally be expected with cutters of different kinds, we find that steel of 250 B. H. N. can be machined with carbon cutters if the speed does not exceed 30 feet per minute and that 18-4-1 high-speed steel can cut the same material at 60 feet per minute, while with carbide cutters a speed of 550 feet per minute can be used. For materials of minimum softness, it indicates that carbon cutters can be run well over 1,000 feet per minute and carbide cutters over 20,000 feet per minute.

A careful study of this chart gives a wide range of information. It does not include chip thickness, which, with the number of teeth in the cutter, is a vital factor in determining the feed to be used. These factors are given elsewhere in this section.

General Rules for Choice of Feed

1. The maximum feed that can be used will be determined either by the power available in the machine, by the number of teeth in the cutter, by the rigidity of the cutter, by work and fixture, or by the finish required. Check these items before starting job.
2. Select the feed per tooth from the table of milling speeds for carbide cutters, remembering that for shallow slotting cuts, etc., the maximum thickness of the undeformed chip may be only 10 to 50 per cent of the feed per tooth. Wherever possible, therefore, on such cuts, use the upper limit given in this table.
3. If the carbide begins to fail rapidly by abrasion, increase the feed per tooth.
4. If the carbide begins to crater too rapidly, reduce the feed per tooth.

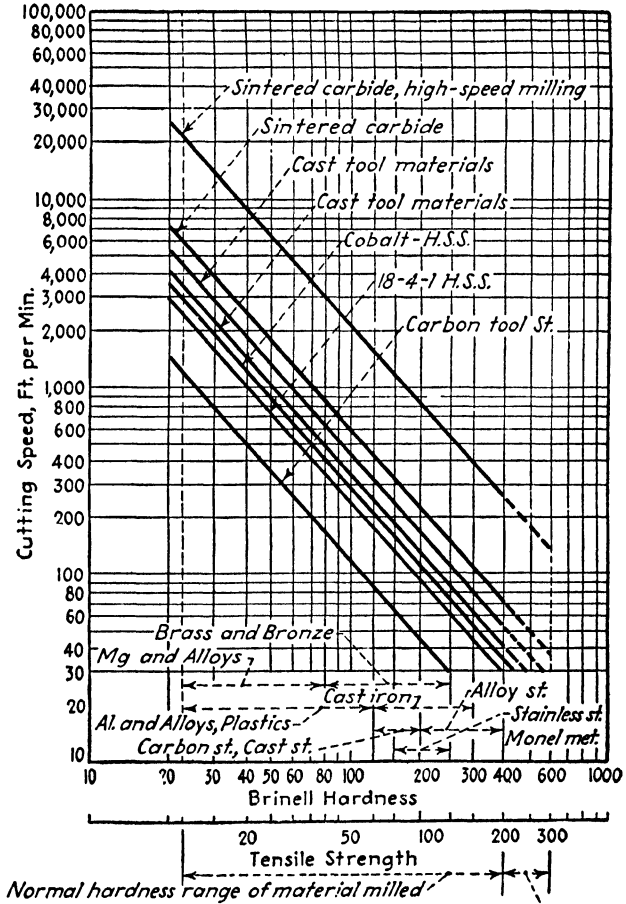


Fig. 14.—A General Guide for Different Tools and Materials.

TABLE 2.—RECOMMENDED MILLING CUTTER ANGLES FOR STEEL

Type of Mill	Work Material	Axial Rake, Degrees	Radial Rake, Degrees	Corner Angle, Degrees	Corresponding True Rake, Degrees
Face or side.	Hard steel (or general purpose)	−10	−10	30 to 45	−13 to −14
Face or side.	Soft steel (under 180 Brinell)	−5	−5	30 to 45	−7
Slotting.	Hard steel (or general purpose)	−5	−10	....	−10
Slotting.	Soft steel (under 180 brinell)	0	−5	....	−5

NOTE.—As indicated in the table, a higher numerical value of negative rake is recommended for the harder steels than for the softer steels.

Where the cutting conditions are extremely severe, axial and radial rake angles of even −20° may be used to advantage. Such severe cutting conditions might be due to hard inclusions in the workpiece or to the chips crowding, which is experienced when the cutter teeth are ground with multiple chambers or a rounded nose.

TABLE 3.—RECOMMENDED CARBIDES FOR STEEL FOR GENERAL USE UNDER AVERAGE CONDITIONS
(Where depth of cut = 0.040 inch or greater)

Work Material	Sintered Carbide			
	Carboloy	Kennametal	Vas Ramet	Firthite
Steel, 100–400 Br..........	78-B	KM	EM	TA

Both harder and softer grades of carbides can be obtained from any of the manufacturers of these materials. The harder grades are more wear-resistant but also more subject to chipping due to impact or vibration. Recommendations for special applications may be obtained from the carbide manufacturers.

Number of Teeth in Cutter.—The maximum number of teeth in the cutter may be limited by the design of the cutter or workpiece, or by the power available at the machine spindle. The following formula should be used to determine the maximum number of teeth in the cutter when limited by power:

$$T = \frac{\text{H.P.} \times K}{d \times w \times f \times N}$$

where

T = number of teeth in cutter.

H.P. = horsepower available at cutter (or maximum permissible power).

K = metal removal factor with dull cutter (cubic inches per minute per H.P.) (see table on page 389-3).

d = depth of cut (inches).

w = width of cut (inches).

f = feed per tooth (inches) (see table on page 385).

N = r.p.m. of cutter $= \frac{12S}{\pi D}$ where S = recommended cutting speed in feet per minute, and D = cutter diameter in inches.

This will permit full utilization of the power of the machine, wherever permissible, while keeping the feed per tooth and cutting speed in accordance with the recommended values. Average values of the factor K for true rake angles of -10 to -14 degrees, for the recommended speeds and feeds, and including a 25 per cent allowance for dulling of the cutter, are given in the following table:

METAL REMOVAL FACTOR

BRINELL HARDNESS	K (DULL CUTTERS)
100	0.80
150	0.70
200	0.65
250	0.60
300	0.55
400	0.50

Cast Iron.—At the present time recommendations for the milling of cast iron still follow the practice which has been in general use for the past several years. Extensive investigations now under way, however, indicate that this practice may be considerably revised in the near future.

Cutting Speed for Cast Iron.—For average grades of cast iron with a Brinell hardness range of 150 to 220, the cutting speed now recommended is from 350 to 250 feet per minute depending on the hardness and uniformity of the material. For chilled castings where the hardness exceeds 300 Brinell, the cutting speed may have to be reduced to about 200 feet per minute to obtain a satisfactory cutter life.

Feed per Tooth for Cast Iron.—For all types of cutters except thin saws, use a feed per tooth of 0.008 to 0.020 inch. Wherever possible, favor the high limit. For thin saws the feed per tooth might be as low as 0.003 inch depending upon depth of cut and the proportions of the saw.

Milling Cutter Angles for Cast Iron.—Axial and radial rake angles now used for milling cast iron vary over a considerable range. In most cases both axial and radial rake are positive, while in other cases the axial rake is positive and the radial rake is negative. It is important that the combination of rake angles be selected with respect to the corner angle so that a desirable value of true (or resultant) rake is obtained.

Values of true rake may be obtained for any combination of axial rake, radial rake, and corner angle from the alignment chart in Fig. 10. For average conditions the true rake should be from +4 to +10 degrees. Corner angles in general use vary from 30 to 45 degrees.

Metal Removal Factor for Cast Iron.—Under average conditions the efficiency of metal removal in cubic inches per minute per horsepower (factor *K* in the equation for number of teeth) is about 1.25. This includes a 25 per cent allowance for dulling of the cutter.

TABLE 4.—RECOMMENDED CARBIDES FOR CAST IRON FOR GENERAL USE UNDER AVERAGE CONDITIONS

Work Material	Sintered Carbide			
	Carboloy	Kenna-metal	Vas Ramet	Firthite
Cast iron.................	44A	K6	2A68	H

It should be noted that both harder and softer grades of carbides for cast iron milling are available from the various manufacturers.

Malleable Iron.—For malleable iron of high ductility which forms a continuous chip, the steel grade carbides should be used. All other recommendations, however, are the same as those given above for cast iron.

Light Alloys.—For aluminum and magnesium alloys, positive rake angles are recommended in practically all applications. Only in the case of some of the more abrasive aluminum alloys does it seem helpful from the standpoint of tool life to resort to negative rake. Cutting speeds from 3,500 to 12,000 or even 15,000 feet per minute are now in use on aluminum alloys, the selection being usually determined by practical considerations other than chip formation, such as cutter vibration (in the case of thin saws), nature of the work and the mounting, and spindle bearing design. Wherever possible, however, the cutting speed should not be less than about 6,000 feet per minute.

SPECIAL MILLING CUTTERS

The Kearney & Trecker engineers have developed a type of face milling cutter which has several novel features. The cutters are of solid carbide inserts clamped in a steel body, instead of having tips brazed to the body, as is customary. Instead of having the blades parallel with the axis of the cutter, they are radial, except for the angle they assume with the face.

One of these cutters is shown in Fig. 15. It was shown in the paper by J. B. Armitage and A. O. Schmidt at the semiannual meeting of the A.S.M.E. at Pittsburgh, Pa., June 19th to 22d, 1944. This has a 30-degree positive secondary rake and a negative primary rake of 6 degrees. The corner angle is 20 degrees. The negative rake is ground on the corner angle but this surface is only a little wider than the chip thickness, which in this case is

0.015 inch. This secures the desired protection of the cutting edge but does not interfere with the chip flow. The chips in this case come off almost flat and are not heated enough to blue them in the least. This is an indication that little or no work is expended in curling the chip. The chips do not impinge on the work surface, which often causes scratches in some milled work.

Another somewhat similar cutter is 8 inches in diameter and has ten teeth. It has a 7-degree axial rake and a 7-degree radial rake, both negative, and a 15-degree corner angle. The tools are solid Kennametal K M. It is felt that cutters arranged in this way can be reground with less waste of carbide and in less time than if they were placed parallel to the axis. Any desired land or clearance can be given the cutters to secure the finish desired. These cutters were designed especially for work on soft steel.

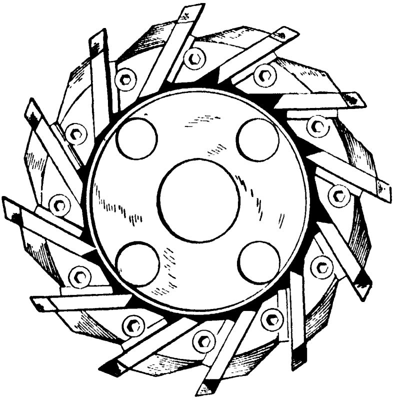


FIG. 15.—Kearney & Trecker Cutter Which Combines Negative and Positive Rakes.

EXAMPLES OF HIGH SPEED MILLING

Examples of high-speed milling using negative rake and negative helix with standard machines are given by J. Q. Holmes, master mechanic, and R. C. Holloway, superintendent of small tools, at the Linden, N.J., plant of the Eastern Aircraft Company. The work is on 4140 chrome molybdenum steel, heat-treated to 40–41 Rockwell C and 180,000 pounds tensile strength. Typical cutter angles are shown in Fig. 16.

Face-milling cutters are used, from 6 to 8 inches in diameter, with ten to fourteen teeth, carbide tipped, Firthite T-16 or its equivalent being used. The illustrations show the angles used. Feeds are from 15 to 21 inches per minute, surface speed is from 800 to 1,285 feet per minute, and chips are 0.002 or 0.003 inch in thickness. At this speed the chips come off the work red hot, but

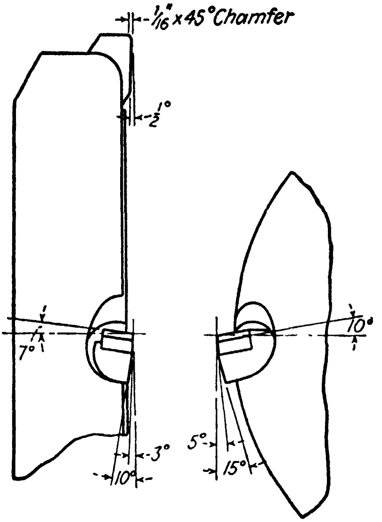


Fig. 16.—Face-Milling Cutter Used in Tests.

Six Typical Hyper-Milling Tests*

Details of Test Conditions	Piece Number					
	1	2	3	4	5	6
Cutter diam., in.	6	6	8	8	6	8
No. of blades	10	10	14	14	10	14
Rake, deg	7	7	7	7	7	7
Helix, deg	10	10	10	10	10	10
Face relief, deg.	3	3	3	3	3	3
Peripheral relief, deg.	6	6	5	5	6	5
Material cut, S.A.E.	4140	4140	4140	4140	4140	4140
Condition	Norm.	Norm.	Norm.	Norm.	H.T.	Norm.
Tensile str., lb. per sq. in.	105M	105M	105M	165M	105M	105M
Cutter speed, rpm	545	597	597	498	498	498
Cutter speed, sfpm	840	875	1285	1075	800	1075
Feed, in. per min	15	15	17.5	17.5	15	21
Feed per tooth per rev.	0.00275	0.0025	0.002	0.0025	0.003	0.003
Depth of cut, in.	7/16½	3/32	5/16	5/16	5/64	5/16
Width of cut, in.	1½	4	0.1¼	3	3	3
Length of cut, in.	1½	6	4	7	3	6
Pieces per grind	112	116	288	106	59	100
Finish of work	Fair	Fine	Fine	Good	Good	Fine
Final cutter condition	Dull	Sl. Dull	Dull	V. Dull	Dull	V. Dull

---

* All made with Lovejoy cutters with Firthite T16 inserted teeth. One pass, dry, in Kearney & Trecker vertical milling machines, on chrome-moly steel.

neither the work nor the cutters get appreciably hot. Milling is done dry.

Cuts range from ⅛ to ½ inch in depth, only one cut being taken in any case. In addition to the increased speed, the finish left by the cutters is very smooth, being almost burnished. Cutters are usually run back over the work, especially when the work is light and may spring slightly under the cut. The table shows the result of six tests and the results being obtained in everyday work with these cutters.

Direction of Feed

Until recent years the work in slab milling has usually been fed against the cutter, as in Fig. 2. This was because the thrust of the cut forced the feed nut against the feed screw so that backlash between them was automatically taken up. When feeding "with the cut," there is a tendency for the cutter to climb on the work. The old way became "conventional" and the new way "climb" milling. Professor O. W. Boston pointed out that as climb milling was likely to become the conventional practice, new names were necessary.

The old or conventional feed is now called "up" or "out" milling, and feeding with the cut, "down" or "in" milling. These terms refer to the upper surface in slab milling. In face milling the tooth action is not quite so clearly defined, depending on the location of the work with reference to the center of the cutter spindle. This has been shown in preceding pages. It is desirable to have the cutter tooth take its maximum chip thickness as it enters the work. This is not possible unless the edge of the work is at, or to one side of, the face mill, which seldom happens. It has been found that cutters stay sharp much longer when they can take a real chip as they enter the work instead of scraping metal until it can get a "bite" into it.

Introduction of the newer method has been delayed by lack of positive feed on many milling machines and lack of appreciation of its desirability. It is interesting to note that Amos H. Brainard, one of the older builders of milling machines, made a machine to "feed with the cut" in 1872.

STANDARD MILLING CUTTERS

Fine-tooth cutters having approximately 4 to 5 teeth per inch of diameter are called "plain mills." Helix angles are between 20 to 30 degrees. They are best qualified for light or shallow cuts and for cuts where there is little tendency to chatter. With their large number of teeth, they will give an excellent cutting life so long as chatter does not develop.

Below 0.75-inch width, plain mills are made with straight teeth or without helix angles. These mills are used for cutting keyways and have been found to give long wear without changing the width of slot cut.

COARSE-TOOTH MILLS

Coarse-tooth mills have from 2 to 3 teeth per inch of diameter and have helix angles from 30 to 45 degrees. Where a plain mill chatters or does not give a smooth cut, the coarse-tooth mill should be used. In general, this mill is good in medium to heavy cuts, and, because of its freedom from chatter, it can remove more metal per minute than plain mills.

This cutter does not do a good job in shoulder milling.

HELICAL MILLS

The heaviest or most difficult cuts should be given to a helical mill with only 1 to 2 teeth per inch of cutter diameter and helix angles of 45 to 60 degrees. The helical mill has the least tendency to chatter of any of the standard mills and is thus used for deep cuts and heavy slabbing cuts. If a single cutter must be used for all plain cuts, then the helical cutter should be selected.

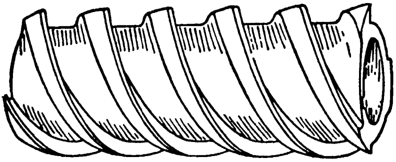


Fig. 17.—Helical Slabbing Cutter

Because of the large helical tooth angle, this cutter has a smooth cutting action and leaves a good finish free from ridges and chatter marks. The steep helix also aids the cutter in producing a uniform or flat surface. There is less springing of both cutter and work, especially of thin plates, than with a plain- or coarse-tooth cutter. For this reason, helical mills are recommended where intermittent cuts or cuts of variable depth and width must be made.

If a shoulder must be milled on a piece where chatter makes a helical mill desirable, use a special helical cutter. Such cutters are standard helical mills except for the last ¼ to ½ inch of width on the end where the tooth-cutting edge makes an acute angle with the side of the cutter. Here the helix angle of the tooth is reduced from 50 degrees to about 10 degrees. Thus for most of the cutter length, the cutting teeth have a steep helix angle which encourages smooth cutting while near the end there is almost no helix which qualifies this corner of the cutter for shoulder milling. See Fig. 17.

FACE MILLS

Inserted-tooth face mills are coarse-tooth cutters which have about 2 teeth per inch of diameter. Since they are mounted directly on the nose of the machine spindle, good cutting rigidity is obtained, and the mills are capable of cutting accurate or flat surfaces. The finish obtained with a face mill is crisscrossed with circular marks.

In many cases the decision to use a face mill or helical mill will be based more on the work than on the cutter. Some pieces can be clamped or supported more readily for face milling than for regular milling. Right-angle surfaces or brackets are perhaps best suited for face milling. Surface plates can be best supported for helical milling. An inserted tooth cutter permits the use of carbide tips on the inserted blades. A face mill is well suited for shoulder milling.

SIDE MILL

A fine-tooth cutter that has side teeth but no helix angle on the top teeth is called a "side mill." With their many straight teeth, the mills are apt to chatter and so are used for light cuts. The side mill produces a slot that has smooth walls or cuts shoulders that have a good finish.

The cutter is reduced in width each time the side teeth are sharpened and thus has a limited life in cutting slots whose widths must be held to close limits. To prolong the life of a cutter, it is common practice to sharpen the side teeth but once in every five sharpenings of the top teeth. This practice is possible because it is the corners of the top teeth which dull most rapidly and these can be renewed by sharpening the top teeth.

HALF-SIDE MILL

This mill has side teeth on one face of the cutter and top teeth that have a helical angle. Because of the helical teeth the cutter has less tendency to chatter than a regular side mill and so can take heavier cuts. It should be used in preference to the side mill when milling to a single shoulder or straddle milling. The depth of the side teeth on a half-side mill is much greater than the side-tooth depth on a regular side mill. This permits a greater number of sharpenings than could be obtained on a single side of a regular side mill. The greater depth also provides more chip space which is helpful when heavy cuts are taken.

STAGGERED-TOOTH SIDE MILL

This coarse-tooth cutter, with side teeth on alternate sides of the mill and with alternating left- and right-hand helix for the top cutting edges, is the heavy-duty cutter of the side-mill series. It is comparatively free from chatter and can take deep cuts even up to the hub without trouble. The cutting action is free, and, when milling deep slots where the side walls are thin, there is little tendency to spring the walls away from the cutter. The finished slot will have walls that are parallel within close limits.

Since the chips removed by the cutter teeth are shorter than the width of slot being milled they do not wedge or jam in the slot. A staggered-tooth cutter works well in slots in soft or ductile materials. For shallow keyways the staggered-tooth side mill with its fewer teeth will not give the life between grinds that can be obtained with a fine-tooth plain mill.

The width of teeth on a staggered-tooth side mill is greater than the width of hub, so two cutters may be mounted together, or interlocked. By using various thicknesses of spacing collars, the two cutters can be adjusted to cut slots of desired widths, and compensation can be made for loss in width due to sharpening the side teeth.

SAWS

The design of saws is dictated by width. Under $\frac{1}{16}$-inch saws are discs with cutting teeth on the outer surface. These saws are dished slightly, but there is no side clearance. For $\frac{1}{16}$-inch thickness or greater, saws can be made with side teeth and are essentially thin side mills. Saws $\frac{8}{16}$ inch in width are made with staggered teeth and closely resemble staggered-tooth side mills.

In many cases it would be desirable to have all saws of the staggered-tooth design. When milling ductile materials, there is a tendency for chips to wedge in the slot, and often the friction produced will break the saw. To avoid this the staggered-tooth saw is used to cut chips that are less than the width of the slot. Operators frequently grind off alternate corners of the saw teeth to secure the same results. This practice makes some difficult cuts possible.

END MILLS

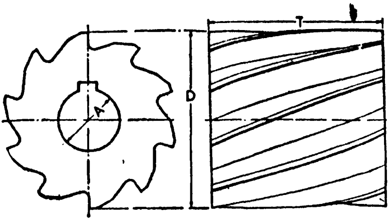
The two-lip end mill must be used whenever the mill is to be sunk into solid metal before milling a slot. The two lips of the mill make a reasonably good drill. With but two teeth, there is ample chip clearance, and the mill can cut slots without jamming with chips. A straight-tooth mill tends to pound as teeth enter and leave the cut. This is especially noticeable in milling a cored slot. To avoid this impact, a helical two-lip mill is often used. The helix angle gives a smoother cutting action and reduces chatter.

In milling a slot in solid metal, it is sometimes noticed that a two-lip helical mill, or four- and six-tooth mills, will leave a low spot or arc in the flat wall surface at that point where the feed was stopped. This is most apt to occur in setups where good rigidity is not obtained. A straight-tooth two-lip mill has less tendency to dig in on entering and leaving a cut than do these other mills.

Six- and eight-tooth helical mills are used where drilling and chip clearance are not problems. These mills have a very smooth cutting action owing to their helix angles and good cutting life owing to the number of teeth used.

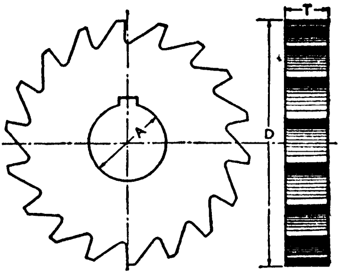
MILLING-CUTTER DIMENSIONS

Standard milling cutters are made to nominal dimensions shown under each illustration. In general, the tolerances are 0.015 inch above and below nominal diameters. Width tolerances vary from basic to 0.020 inch oversize in some cases and from slightly below basic to 0.020 inch oversize in others. Hole tolerances are all from basic to 0.001 inch oversize. Makers list all details.



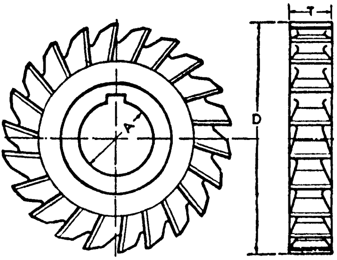
$D = 2\frac{1}{2}$ to $4\frac{1}{2}$ inches.
$T = 2$ to 12 inches.
$A = 1$ to 2 inches.
Made in eight sizes.

Plain Mills, Heavy Duty



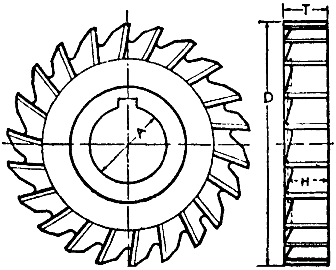
$D = 2\frac{1}{4}$ to 4 inches.
$T = \frac{1}{2}$ to 6 inches.
$A = \frac{7}{8}$ to $1\frac{1}{2}$ inches.
Cutters wider than $\frac{3}{4}$ inch have helical teeth.
Made in sixteen sizes

Plain Mills, Light Duty



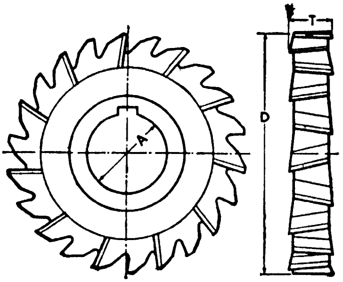
$D = 2$ to 4 inches.
$T = \frac{3}{16}$ to $\frac{7}{8}$ inch.
$A = \frac{1}{2}$ to $1\frac{1}{4}$ inches.
Made in seventeen sizes.

Straddle Mills



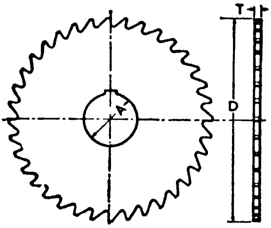
$D = 4$ to 8 inches.
$T = \frac{1}{2}$ to $1\frac{1}{4}$ inches.
$A = 1\frac{1}{4}$ to $1\frac{1}{2}$ inches.
$H = \frac{7}{16}$ to $1\frac{1}{8}$ inches.
Made in ten sizes.

Half-Side Mills



D = 2½ to 8 inches.
T = ¼ to 1 inch.
A = ⅞ to 1½ inches.
Side teeth do not cut.
Made in thirteen sizes.

Stagger-Tooth Mills

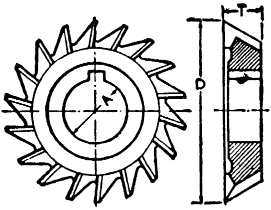


D = 2½ to 8 inches.
T = 1/32 to 3/16 inch.
A = ⅞ to 1¼ inches.

The 5-, 6-, 7- and 8-inch saws, ⅛ inch thick, are also made with 1¼-inch hole.

Made in fourteen sizes.

Slitting Saws

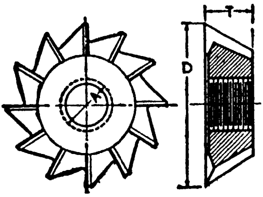


D = 2½ to 3 inches.
T = ½ inch.
A = ⅞ to 1¼ inches.

Angular cutters furnished either righ or left hand with included angle of 45 o 60 degrees; tolerance for angle, ± 1 minutes.

Made in three sizes.

Single-Angle Mills

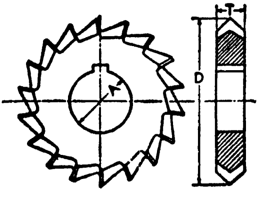


D = 1¼ to 1⅝ inches.
T = 7/16 to 9/16 inch.
A = ⅜ to ½ inch.

Cutters furnished either right- or left-hand teeth and either right- or left-hand thread. They have an included angle of 60 degrees; tolerance for angle, ± 10 minutes.

Made in two sizes.

Single-Angle—Threaded Hole

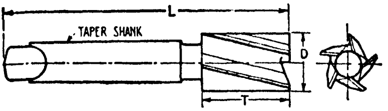


D = 2¾ inches.
T = ½ inch.
A = 1 inch.

Double-angle cutters furnished with an included angle of either 45, 60 or 90 degrees; tolerance for angle, ± 10 minutes.

Made in one size.

Double-Angle Mills

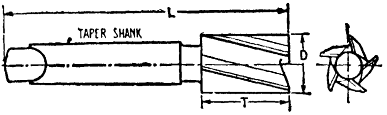


End Mills—Brown and Sharpe

$D = \frac{1}{4}$ to 2 inches.
$T = \frac{3}{8}$ to $2\frac{3}{4}$ inches.
$L = 2\frac{13}{16}$ to 8 inches.

$\frac{1}{4}$ inch has Brown and Sharpe No. 5 taper shank. $\frac{1}{2}$ inch can have No. 5 or No. 7. 1 inch has No. 7. $1\frac{1}{2}$ inch and 2 inches have No. 9.

Made in six sizes.



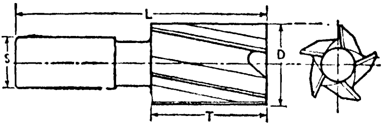
End Mills—Morse

$D = \frac{1}{4}$ to $1\frac{1}{4}$ inches.
$T = \frac{5}{8}$ to 2 inches.
$L = 3\frac{1}{2}$ to $6\frac{5}{16}$ inches.

$\frac{1}{4}$ inch has No. 1 Morse shank. $\frac{1}{2}$ inch can have No. 1 or No. 2. 1 inch has No. 2. $\frac{3}{4}$ and $1\frac{1}{4}$ inches have No. 3.

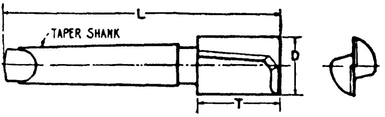
Right- or left-hand helix.

Made in six sizes.



End Mills—Straight Shank

$D = \frac{1}{8}$ to $\frac{3}{4}$ inch.
$T = \frac{5}{16}$ to $1\frac{1}{4}$ inches.
$S = \frac{1}{8}$ to $\frac{3}{4}$ inch.
$L = 1\frac{1}{4}$ to $2\frac{5}{8}$ inches.
Right- or left-hand helix.
Made in twelve sizes.



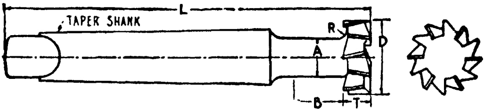
Two-Lipped End Mill

$D = \frac{1}{4}$ to 2 inches.
$T = \frac{3}{8}$ to $2\frac{1}{4}$ inches.
$L = 2\frac{9}{16}$ to 8 inches.

$\frac{1}{4}$ and $\frac{5}{16}$ inch have No. 5 shank. 1 and 2 inches have No. 9 shank, Brown and Sharpe.

Right- or left-hand helix.

Made in six sizes.



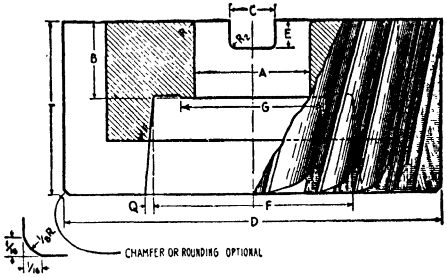
T—Slot Mill. Brown and Sharpe Shank

$D = \frac{1}{4}$ to $1\frac{1}{2}$ inches.
$T = 0.229$ to 1.343 inches.
$A = 0.260$ to 1.531 inches.
$B = \frac{3}{8}$ to $1\frac{11}{16}$ inches.
$R = 0.007$ to $\frac{1}{64}$ inch.
$L = 2\frac{5}{8}$ to $10\frac{5}{8}$ inches.

$\frac{1}{4}$ and $\frac{5}{16}$ inch have No. 5 shank. $\frac{3}{8}$ to $\frac{5}{8}$ inch have No. 7 shank. $\frac{3}{4}$ to $1\frac{1}{4}$ inches have No. 9 shank. $1\frac{1}{2}$ inches have No. 10 shank.

Neck diameters A are made for Standard T slots.

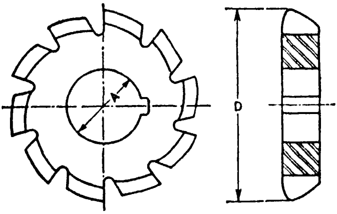
Made in nine sizes.



$D = 1\frac{1}{4}$ to 6 inches.
$T = 1$ to $2\frac{1}{4}$ inches.
$A = 0.5$ to 2 inches.
$B = \frac{5}{8}$ to 1 inch.
$C = 0.262$ to 0.762 inch.
$E = \frac{5}{32}$ to $\frac{7}{16}$ inch.

$R = \frac{1}{64}$ to $\frac{1}{16}$ inch.
$F = \frac{11}{16}$ to $2\frac{13}{16}$ inches.
$G = \frac{5}{8}$ to $2\frac{1}{2}$ inches.
$Q = 0$ to 15 degrees.
Right- or left-hand helix.
Made in fourteen sizes.

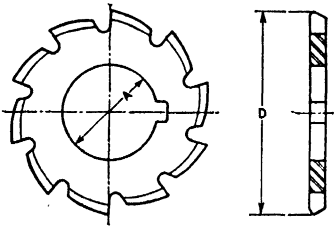
Shell End Mills



Fluting Reamers

$D = 2\frac{1}{4}$ to $3\frac{1}{4}$ inches.
$A = 1$ to $1\frac{1}{4}$ inches.

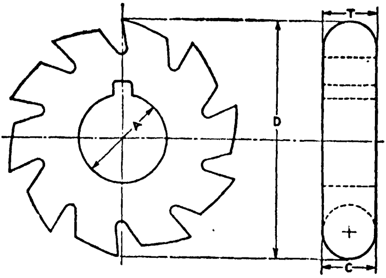
Cutter Number	Diameter of Reamer, Inches	Number of Teeth in Reamer
1	$\frac{1}{8}$ to $\frac{3}{16}$	6
2	$\frac{1}{4}$ to $\frac{5}{16}$	6
3	$\frac{3}{8}$ to $\frac{7}{16}$	6
4	$\frac{1}{2}$ to $\frac{11}{16}$	6–8
5	$\frac{3}{4}$ to 1	8
6	$1\frac{1}{16}$ to $1\frac{1}{2}$	10
7	$1\frac{9}{16}$ to $2\frac{1}{8}$	12
8	$2\frac{1}{4}$ to 3	14



Fluting Tops

$D = 2$ to $3\frac{3}{8}$ inches.
$A = 1$ to $1\frac{1}{4}$ inches.

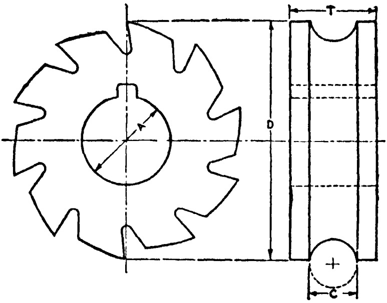
Cutter Number	Diameter of Tap, Inches	Number of Flutes in Tap
1	0 to $\frac{1}{8}$	4
2	$\frac{5}{32}$ to $\frac{1}{4}$	4
3	$\frac{9}{32}$ to $\frac{3}{8}$	4
4	$\frac{7}{16}$ to $\frac{5}{8}$	4
5	$\frac{11}{16}$ to $\frac{7}{8}$	4
6	$\frac{15}{16}$ to $1\frac{1}{4}$	4
7	$1\frac{5}{16}$ to $1\frac{5}{8}$	4
8	$1\frac{11}{16}$ to 2	



D = 2 to 3¼ inches.
A = ⅞ to 1 inch.
C = ⅛ to 1 inch.

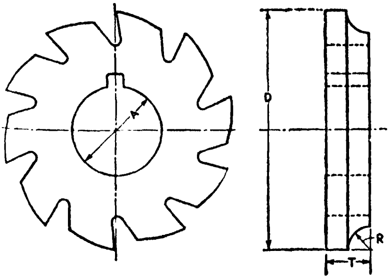
T = ⅛ to 1 inch.
Made in eleven sizes.
Radial or hooked teeth optional.

Convex Mills



D = 2 to 3¼ inches.
T = ¼ to 1 9/16 inches.
A = ⅞ to 1 inch.
C = ⅛ to 1 inch.
Made in eleven sizes.
Radial or hooked teeth optional.

Concave Mills



D = 2 to 3½ inches.
T = ¼ to 5/16 inch.
A = ⅞ to 1 inch.
R = ⅛ to ⅝ inch.
Made in five sizes.
Right or left hand.
Radial or hooked teeth optional.

Corner-Rounding Mills

SPROCKET-WHEEL CUTTERS FOR ROLLER CHAINS, AMERICAN NATIONAL STANDARD TOOTH FORM

Circular Pitch, Inches	Diameter of Roll, Inches	Number of Teeth in Sprocket	Diameter of Cutter, Inches	Width of Cutter, Inches	Size of Hole, Inches
⅜	0.200	6	2¾	15/32	1
		7 to 8	2¾	15/32	
		9 to 11	2¾	15/32	
		12 to 17	2¾	7/16	
		18 to 34	2¾	7/16	
		35 and over	2¾	13/32	
½ to ⅝	0.313	6	3	¾	1
		7 to 8	3	¾	
		9 to 11	3⅛	¾	
		12 to 17	3⅛	¾	
		18 to 34	3⅛	23/32	
		35 and over	3⅛	11/16	
⅝	0.400	6	3⅛	¾	1
		7 to 8	3⅛	¾	
		9 to 11	3¼	¾	
		12 to 17	3¼	¾	
		18 to 34	3¼	23/32	
		35 and over	3¼	11/16	
¾	0.469	6	3¼	29/32	1
		7 to 8	3¼	29/32	
		9 to 11	3⅜	29/32	
		12 to 17	3⅜	⅞	
		18 to 34	3⅜	27/32	
		35 and over	3⅜	13/16	
1	0.563	6	3¾	1¼	1¼
		7 to 8	3⅞	1¼	
		9 to 11	3⅞	1 3/16	
		12 to 17	4	1 5/32	
		18 to 34	4	1⅛	
		35 and over	4	1 3/32	
1 to 1¼	0.625	6	3⅞	1½	1¼
		7 to 8	4	1½	
		9 to 11	4⅛	1 15/32	
		12 to 17	4⅛	1 15/32	
		18 to 34	4¼	1 13/32	
		35 and over	4¼	1 11/32	
1¼ to 1½	0.750	6	4¼	1 13/16	1¼
		7 to 8	4⅜	1 13/16	
		9 to 11	4½	1 25/32	
		12 to 17	4½	1¾	
		18 to 34	4⅝	1 11/16	
		35 and over	4⅝	1⅝	
1½	0.875	6	4⅜	1 13/16	1¼
		7 to 8	4½	1 13/16	
		9 to 11	4⅝	1 25/32	
		12 to 17	4⅝	1¾	
		18 to 34	4¾	1 11/16	
		35 and over	4¾	1⅝	

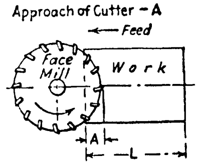
ESTIMATING MILLING TIME

The Cincinnati Milling Machine Company gives the following formula for estimating time required for milling:

$$\text{Actual milling time in minutes} = \frac{\text{length of cut} + \text{approach of cutter} + \text{overtravel}}{\text{feed in inches per minute}}$$

Tables for allowance for the approach of the milling cutter to the work follow. Length of cut is in inches. The overtravel of the cutter is the sum of the distance the table must travel after the feed is engaged before any cutting action takes place and the extra travel required at the end of the cut to take care of any variation in the length of the work.

TABLE. 5.—APPROACH OF CUTTER FOR END MILLS AND FACE MILLS*

Diameter of Mill	Width of Cut, Inches											
	1	2	3	4	5	6	7	8	9	10	11	12
1	0.5								 Approach of Cutter – A Feed Face Mill Work A L			
1½	0.192											
2	0.135	1.										
2½	0.105	0.5										
3	0.09	0.37	1.5									
4	0.07	0.27	0.68	2.								
5	0.05	0.24	0.5	1.	2.5							
6	0.04	0.18	0.4	0.77	1.34	3.						
7½	0.04	0.14	0.32	0.59	0.96	1.51	2.63					
8	0.033	0.13	0.291	0.54	0.88	1.36	2.07	4.				
10	0.025	0.10	0.23	0.43	0.56	1.00	1.43	2.	2.82	5.		
12	0.020	0.08	0.19	0.35	0.54	0.81	1.13	1.53	2.04	2.69	3.6	6

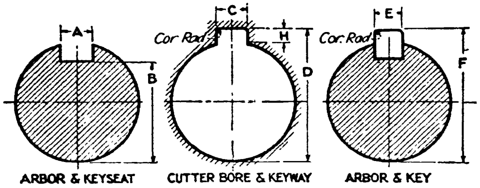
* Follow down the first column to the diameter of cutter used. Follow across to the right to the column under the width of cut. The figure given is the "approach" of the cutter. See cut.

EXAMPLE.—Calculate actual cutting time of a cast-iron bracket where the length of cut is 11 inches, width of cut is 8 inches, diameter of face mill is 10 inches, overtravel is ½ inch, and feed is 9¼ inches per minute. Table 5 gives 2 inches as the approach of a 10-inch cutter on 8-inch work before it cuts the full width of the work, and the same distance must be allowed at the other end if the cutter is to clear the work as is usually necessary to prevent marks on the surface showing where the cut stopped. This makes the formula read

$$\text{Time} = \frac{11 + 2 + 2 + 0.50}{9.25} = 1.67 \text{ minutes}$$

To this must be added the total handling, which includes getting the work out of the machine and putting in a new piece of work. The faster the milling, the more necessary is quick handling to reduce the total floor-to-floor time of the operation.

KEYS AND KEYWAYS FOR MILLING CUTTERS AND ARBORS



KEYSEAT, KEYWAY, AND KEY DIMENSIONS

Diameter, Arbor	Nominal Size Key (Square)	Arbor and Keyseat				Bore and Keyway[1]					Arbor and Key[1]			
		A		B		C		D	H	Correct Radius	E		F	
		Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Minimum	Nominal		Maximum	Minimum	Maximum	Minimum
$\frac{1}{2}$	$\frac{3}{32}$	0.0947	0.0937	0.4531	0.4481	0.106	0.099	0.5578	$\frac{3}{64}$	0.020	0.0932	0.0927	0.5468	0.5408
$\frac{5}{8}$	$\frac{1}{8}$	0.126	0.125	0.5625	0.5575	0.137	0.130	0.6985	$\frac{1}{16}$	$\frac{1}{32}$	0.1245	0.1240	0.6875	0.6815
$\frac{3}{4}$	$\frac{1}{8}$	0.126	0.125	0.6875	0.6825	0.137	0.130	0.8225	$\frac{1}{16}$	$\frac{1}{32}$	0.1245	0.1240	0.8125	0.8065
$\frac{7}{8}$	$\frac{1}{8}$	0.126	0.125	0.8125	0.8075	0.137	0.130	0.9475	$\frac{1}{16}$	$\frac{1}{32}$	0.1245	0.1240	0.9375	0.9315
1	$\frac{1}{4}$	0.251	0.250	0.8438	0.8388	0.262	0.255	1.104	$\frac{3}{32}$	$\frac{3}{64}$	0.2495	0.2490	1.094	1.088
1$\frac{1}{4}$	$\frac{5}{16}$	0.3135	0.3125	1.063	1.058	0.325	0.318	1.385	$\frac{1}{8}$	$\frac{1}{16}$	0.3120	0.3115	1.375	1.369
1$\frac{1}{2}$	$\frac{3}{8}$	0.376	0.375	1.281	1.276	0.410	0.385	1.666	$\frac{5}{32}$	$\frac{1}{16}$	0.3745	0.3740	1.656	1.650
1$\frac{3}{4}$	$\frac{7}{16}$	0.4385	0.4375	1.500	1.495	0.473	0.448	1.948	$\frac{3}{16}$	$\frac{1}{16}$	0.4370	0.4365	1.938	1.932
2	$\frac{1}{2}$	0.501	0.500	1.687	1.682	0.535	0.510	2.198	$\frac{3}{16}$	$\frac{1}{16}$	0.4995	0.4990	2.188	2.182
2$\frac{1}{2}$	$\frac{5}{8}$	0.626	0.625	2.094	2.089	0.660	0.635	2.733	$\frac{7}{32}$	$\frac{1}{16}$	0.6245	0.6240	2.718	2.712
3	$\frac{3}{4}$	0.751	0.750	2.500	2.495	0.785	0.760	3.265	$\frac{1}{4}$	$\frac{3}{32}$	0.7495	0.7490	3.250	3.244
3$\frac{1}{2}$	$\frac{7}{8}$	0.876	0.875	3.000	2.995	0.910	0.885	3.890	$\frac{3}{8}$	$\frac{3}{32}$	0.8745	0.8740	3.875	3.869
4	1	1.001	1.000	3.375	3.370	1.035	1.010	4.390	$\frac{3}{8}$	$\frac{3}{32}$	0.9995	0.9990	4.375	4.369
4$\frac{1}{2}$	1$\frac{1}{8}$	1.126	1.125	3.813	3.808	1.160	1.135	4.953	$\frac{7}{16}$	$\frac{1}{8}$	1.1245	1.1240	4.938	4.932
5	1$\frac{1}{4}$	1.251	1.250	4.250	4.245	1.285	1.260	5.515	$\frac{1}{2}$	$\frac{1}{8}$	1.2495	1.2490	5.500	5.494

[1] NOTE: A difference between the overall cutter bore and keyway D and the arbor-and-key dimension F, of 0.010 inch for arbor diameters up to 2 inches, and 0.015 inch on arbor diameters larger than 2 inches, is allowed.

SPROCKET-WHEEL CUTTERS FOR ROLLER CHAINS, AMERICAN NATIONAL STANDARD TOOTH FORM

Circular Pitch, Inches	Diameter of Roll, Inches	Number of Teeth in Sprocket	Diameter of Cutter, Inches	Width of Cutter, Inches	Size of Hole, Inches
1¾	1.000	6	5	2 5/32	1½
		7 to 8	5⅛	2 3/32	
		9 to 11	5¼	2 1/16	
		12 to 17	5⅜	2 1/32	
		18 to 34	5½	1 31/32	
		35 and over	5⅝	1⅞	
2	1.125	6	5⅜	2 13/32	1½
		7 to 8	5½	2 13/32	
		9 to 11	5⅝	2⅜	
		12 to 17	5¾	2 5/16	
		18 to 34	5⅞	2¼	
		35 and over	5⅞	2 5/32	
2½	1.5625	6	6⅜	3	1¾
		7 to 8	6⅝	3	
		9 to 11	6¾	2 15/16	
		12 to 17	6⅞	2 29/32	
		18 to 34	7	2¾	
		35 and over	7⅛	2 11/16	
3	1.900	6	7½	3 19/32	2
		7 to 8	7¾	3 19/32	
		9 to 11	7⅞	3 17/32	
		12 to 17	8	3 15/32	
		18 to 34	8	3 11/32	
		35 and over	8⅛	3 7/32	

All dimensions given in inches.

AIR CLAMPS

Every decrease in machining time makes the time required for handling more important. Shops using high-speed milling find it advantageous to use compressed air cylinders even on small work handling fixtures. They buy commercial air cylinders, keep them on hand, and incorporate them into all new fixture designs. The time saved in floor-to-floor handling must be considered with every increase in the speed of machining of all kinds.

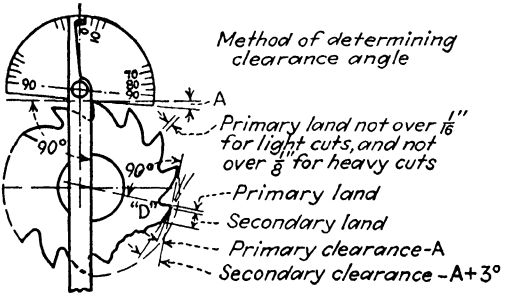
STELLITE CUTTERS

Average cutting speeds for milling cast iron and malleable iron with Stellite-J-metal are: light rough milling, 150 to 250 feet per minute; light-finish milling, 150 to 300 feet per minute; heavy rough milling, 80 to 140 feet per minute; heavy finish milling, 130 to 160 feet per minute.

FORM AND PROFILE CUTTERS

The difference between form and profile cutters should be clearly understood. *Form* cutters have the cutting edge formed by backing off the metal behind the edge so as to maintain the same contour from the surface to the flute of the cutter. By grinding these cutters on the face of the teeth, the same contour is maintained during the life of the cutter.

Profile cutters are ground on the narrow surface back of the cutting edge. This is known as the primary clearance. This clearance back of the cutting edge can be measured either by a protractor or by a dial indicator. The protractor method is shown in Fig. 18. This also shows the primary and secondary lands and gives dimensions. The secondary land backs up the cutting edge with more stock.


Method of determining clearance angle
90
70
80
90
A
Primary land not over $\frac{1}{16}''$ for light cuts, and not over $\frac{1}{8}''$ for heavy cuts
90°
90°
"D"
Primary land
Secondary land
Primary clearance-A
Secondary clearance -A+3°

When tooth widens after repeated grindings as at "D"- make secondary clearance 3° greater than primary to clear heel of tooth.
Keep primary land narrow.

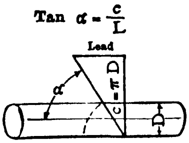
FIG. 18.—Using Protractor to Get Angle

To use a dial indicator the formula, on the basis of a $\frac{1}{16}$-inch primary land, is:

Tangent of 1 degree divided by 16. Tangent of 1 degree is 0.01746. Dividing by 16 gives 0.00109. A dial indicator will show a reading of 0.00109 inch on a $\frac{1}{16}$ land for each degree of clearance. For a 5-degree clearance, the reading would be 0.00545 inch, regardless of the cutter diameter.

CUTTING HELICES ON UNIVERSAL MILLING MACHINES

The following tables show the leads of cutter helices used by the Brown & Sharpe Mfg. Co., together with pitches and approximate angles for cutting helices on universal milling machines. The necessary explanations are given in the note in the tables, these being made clear by the accompanying diagram.



Leads of B. & S. Cutter Spirals (Helices)

The leads of the Brown & Sharpe Cutter Helices are as follows:

$$\text{Tan } \alpha = \frac{C}{L}$$

Diam. of Cutter	Lead	Diam. of Cutter	Lead
½″	7.29″	2″	31.5″
⅝– ¾″	9.52″	2¼–2½″	36″
⅞″	13.71″	2¾–3″	48″
1 –1¼″	17.14″	3½–3¾″	60″
1½″	23.33″	4″	68.57″
1¾″	28″		

Formulas for Revolutions of Cutter

$$\text{Revolutions per minute} = \frac{3.82 \times \text{cutting speed selected}}{\text{cutter diameter in inches}}$$

Formula for cutter feed in inches per minute

$$\text{Feed} = \frac{\text{horsepower applied} \times \text{constant } K}{\text{total width of cut} \times \text{depth of cut}}$$

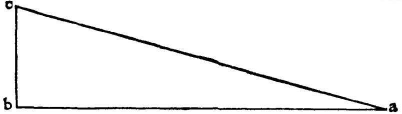
Values of Constant *K*

Material	Bed-Type Machine	Knee and Column Machine
Cast iron	1.50	1.00
Mild steel	0.75	0.50
High-carbon steel	0.65 to 0.75	0.40
Alloy steel	0.50 to 0.75	0.35
Malleable iron	1.20	0.75
Brass and bronze	2.00 to 3.00	2.00
Aluminum	2.00 to 2.50	2.00

TABLE 6.—CHANGE GEARS, APPROXIMATE ANGLES, AND ENGLISH LEADS FOR CUTTING HELICES

Twelve change gears are furnished with each Universal miller as follows: 24, 24, 28, 32, 40, 44, 48, 56, 64, 72, 86, and 100 teeth

Lead of Spiral Inches	Gear on Worm	1st Intermediate Gear	2nd Intermediate Gear	Gear for Screw	1st Intermediate Gear Drives the Gear on Worm 2nd Intermediate Gear Drives the Gear for Screw																							
					Diameter of Work, Inches																							
	A	B	C	D	⅛	¼	⅜	½	⅝	¾	⅞	1	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4½	5	5½	6
	Driven	Driver	Driven	Driver																								
0.67	24	86	24	100	30¼																							
0.78	24	86	28	100	26	44½																						
0.89	24	86	32	100	23½	41																						
1.12	24	86	40	100	19	34½																						
1.34	24	86	48	100	16	30¼	41½																					
1.46	24	64	28	72	14¾	28	38½																					
1.56	28	86	48	100	13¾	26½	37																					
1.67	24	64	32	72	12¾	25	34¾	43¼																				
1.94	28	64	32	72	11¼	21¾	31	39	45																			
2.08	24	64	40	72	10¼	20½	29½	37	43¼																			
2.22	32	56	28	72	9¾	19¼	27½	35	41¼																			
2.50	24	64	48	72	8¾	17	25	32	38	43¼																		
2.78	32	64	40	72	8	15½	23	29½	35¼	40½	44¾																	
2.92	32	56	44	86	7½	15	21¾	28¼	34	39	43¼																	
3.24	28	48	40	72	6¾	13¼	19¾	25¾	31¼	36	40½	44¼																
3.70	32	48	40	72	6	11¾	17½	23	28	32½	36½	40½																
3.89	32	64	56	72	5½	11¼	16¾	22	26¾	31¼	35¼	39																
4.17	40	64	48	72	5¼	10½	15¾	20½	25¼	29½	33½	37	43¼															
4.46	32	40	48	86	4¾	9¾	14¾	19¼	22¾	27¾	31½	35	41½															
4.86	40	64	56	72	4½	9	13½	17¾	22	25¾	29½	33	39	44¼														
5.33	32	40	48	72	4	8¼	12¼	16½	20¼	23¾	27¼	30½	36½	44¼														
5.44	56	40	28	72	4	8	12	16	20	23½	26¾	30	36	41														
6.12	56	40	28	64	3½	7¼	11	14½	17¾	21	24¼	27	33	37¾	42													



To find the angle for cutters of a larger diameter than given in the table, make a drawing as shown in the diagram, the angle *b* being a right angle. Let *b c* equal the circumference. Let *a b* equal the pitch. Connect *c a* by a line, and measure the angle *a* with a protractor; or divide the circumference by the lead and the quotient will be the tangent of the angle. Find the angle in a table of tangents.

Approximate Angle in Degrees for setting Milling Machine Table.

These tables are of special convenience for quickly setting the machine with proper change gears when the angle of spiral and the diameter of a piece of work are known. For example: To cut a spiral mill 4 inches diameter, 25 degree angle: Follow down the 4-inch column to the nearest angle 25¼, and the change gears are 64, 28, 56, and 48.

$$\frac{\text{Lead}}{10} = \frac{\text{Driven}}{\text{Drivers}} = \frac{\text{2d X Worm}}{\text{1st X Screw}}$$

TABLE 6.—CHANGE GEARS, APPROXIMATE ANGLES, AND ENGLISH LEADS FOR CUTTING HELICES—*Continued*

Lead of Spiral Inches	Gear on Worm	1st Intermediate Gear	2nd Intermediate Gear	Gear for Screw	1st Intermediate Gear Drives the Gear on Worm 2nd Intermediate Gear Drives the Gear for Screw																							
					Diameter of Work, Inches																							
	A	B	C	D	⅛	¼	⅜	½	⅝	¾	⅞	1	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4½	5	5½	6
6.22	64	40	28	72	3½	7	10¾	14¼	17½	20¾	23¾	26¾	32½	37¼	41½													
6.48	40	48	56	72	3¼	6¾	10¼	13½	16¾	20	23	25¾	31½	36¼	40¼	44¼												
6.67	64	56	28	48	3¼	6½	10	13¼	16½	19½	22½	25¼	30¾	35¼	39½	43½												
7.29	56	64	40	48	3	6¼	9¼	12¼	15	18	20½	23½	28½	33	37	41	44¼											
7.41	40	48	64	72	3	6	9	12	14¾	17¾	20¼	22¾	28¼	32½	36½	40¼	43¾											
7.62	48	56	64	72	2¾	5¾	8¾	11½	14½	17¼	19¾	22¼	27½	32	36	39½	43											
8.33	48	32	40	72	2½	5¼	8	10½	13¼	15¾	18¼	20½	25½	29½	33½	37	40½	43½										
8.95	86	48	28	56	2½	5	7½	10	12½	14¾	17	19¼	24	28	31¾	35¼	38½	41¼	44									
9.33	48	40	56	72	2¼	4¾	7¼	9½	11¾	14	16¼	18½	23	27	30½	34	37½	40¼	43									
9.52	64	56	40	48	2¼	4½	7	9¼	11½	13¾	16	18¼	22½	26½	30	33½	36½	39½	42¼	45								
10.29	72	40	32	56	2	4¼	6½	8¾	10¾	12¾	15	17¼	21	24¾	28¼	31½	34½	37½	40	42½	45							
10.37	56	48	64	72	2	4¼	6½	8½	10½	12¾	14¾	17	20¾	24½	28	31¼	34¼	37¼	39¾	42¼	44¾							
10.50	56	64	48	40	2	4¼	6¼	8½	10½	12½	14½	16¾	20½	24¼	27¾	31	34	36¾	39½	42	44¼							
10.67	48	40	64	72	2	4	6¼	8¼	10¼	12¼	14¼	16½	20¼	24	27¼	30½	33½	36½	39	41½	43¾							
10.94	56	32	40	64	2	4	6	8¼	10¼	12	14	16¼	20	23½	26¾	30	33	35¾	38¼	40¾	43							
11.11	64	32	40	72	2	4	6	8	10	11¾	13¾	16	19¾	23	26½	29½	32½	35¼	38	40¼	42½	44¾						
11 66	56	32	48	72	1¾	3¾	5¾	7½	9½	11¼	13¼	15¾	18¾	22	25¼	28½	31¼	34	36½	39	41¼	43½						
12.00	72	40	32	48	1¾	3¾	5½	7¼	9¼	11	12¾	15	18¼	21½	24¾	27¾	30½	33¼	35¾	38	40¼	42½	44¾					
13 12	56	32	48	64	1½	3½	5¼	6¾	8½	10¼	11¾	13½	16¾	20	22¾	25¾	28¼	31	33¼	35¾	37¾	40	42	43¾				
13.33	64	32	48	72	1½	3¼	5	6½	8¼	10	11½	13¼	16½	19½	22½	25½	28	30½	33	35¼	37½	39½	41½	43¼	46¾	49¼	52¼	
13.71	64	56	48	40	1½	3¼	4¾	6½	8	9¾	11¼	13	16	19	22	24¾	27½	30	32¼	34½	36½	38¾	40¾	42½	45¾	49	51¾	
15.24	64	28	48	72	1½	3	4½	5¾	7¼	8¾	10¼	11¾	14½	17¼	20	22½	25	27¼	29½	31¾	34	35¾	37¾	39½	42¾	46	48½	51
15.56	64	32	56	72	1¼	2¾	4¼	5¾	7¼	8¾	10	11½	14¼	17	19½	22	24½	27	29	31¼	33¼	35¼	37	39	42¼	45¼	48	50½
15.75	72	64	56	40	1¼	2¾	4¼	5½	7	8½	9¾	11¼	14	16¾	19¼	21¾	24¼	26½	28¾	31	33	35	36¾	38½	42	45	47½	50

TABLE 6.—CHANGE GEARS, APPROXIMATE ANGLES, AND ENGLISH LEADS FOR CUTTING HELICES—*Continued*

Lead of Spiral Inches	Gear on Worm	1st Intermediate Gear	2nd Intermediate Gear	Gear for Screw	1st Intermediate Gear Drives the Gear on Worm 2nd Intermediate Gear Drives the Gear for Screw																							
					Diameter of Work, Inches																							
	A	B	C	D	⅛	¼	⅜	½	⅝	¾	⅞	1	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4½	5	5½	6
16.87	72	32	48	64	1¼	2½	4	5¼	6¾	7¾	9¼	10½	13¼	15¾	18¼	20½	22¾	25	27	29¼	31¼	33¼	35	36½	39¾	43	45¾	48¼
17.14	72	56	64	48	1¼	2½	4	5¼	6½	7¾	9	10¼	13	15½	17¾	20¼	22¼	24¾	26¾	29	30¾	32¾	34½	36	39½	42½	45¼	47¾
18.75	72	32	40	48	1	2¼	3½	4¾	6	7¼	8¼	9½	12	14¼	16¼	18½	20¾	22¾	25	26¾	28½	30¼	32	33¾	37	39¾	42¾	45
19.29	72	32	48	56	1	2¼	3½	4½	5¾	7	8	9¼	11½	13¾	16	18¼	20¼	22¼	24	26	28	29¾	31½	33	36¼	38¾	42	44½
19.59	64	28	48	56	1	2¼	3¼	4½	5¾	6¾	8	9¼	11½	13½	15¾	18	20	22	23¾	25¾	27½	29¼	31	32¾	35¾	38¾	41½	44
19.69	72	32	56	64	1	2¼	3¼	4½	5¾	6¾	8	9	11½	13½	15¾	17¾	20	21¾	23¾	25½	27½	29¼	31	32½	35¾	38½	41¼	43¾
21.43	72	28	40	48	1	2	3¼	4¼	5¼	6¼	7½	8½	10½	12½	14½	16½	18½	20¼	22	23¾	25½	27¼	29	30¼	33½	36¼	38¾	41¼
22.50	72	28	56	64	1	2	3	4	5	6	7	8	10	12	13¾	15¾	17½	19¼	21	22¾	24½	27	27¾	29¼	32¼	35	37½	40
23.33	64	48	56	32	1	2	3	4	5	5¾	6¾	7¾	9¾	11½	13¼	15¼	17	18¾	20¼	22	23½	25¼	27	28¼	31¼	34	36¾	39
26.25	72	48	56	32	1	1¾	2¾	3½	4¼	5	6	7	8½	10¼	12	13½	15	16¾	18¼	19¾	21¼	22¾	24¼	25½	28¼	31	33¼	35¾
26.67	64	28	56	48	¾	1¾	2¾	3½	4¼	5	6	6¾	8½	10	11¾	13¼	14¾	16½	18	19½	21	22¼	23¾	25¼	28	30½	31¼	35¼
28.00	64	40	56	32	¾	1¾	2½	3¼	4	4¾	5¾	6½	8	9½	11¼	12¾	14¼	15¾	17¼	18¾	20	21½	22¾	24	26¾	29¼	31¾	34
	Driven	Driver	Driven	Driver																								
30.86	72	28	48	40	¾	1½	2¼	3	3¾	4½	5	5¾	7¼	8¾	10	11½	13	14¼	15½	17	18½	19½	21	22	26	27	29¼	31½
31.50	72	40	56	32	¾	1½	2¼	3	3½	4¼	5	5¾	7¼	8½	10	11¼	12¾	14	15¼	16½	18	19¼	20½	21¾	24¼	26½	28¾	31
36.00	72	40	64	32	½	1¼	2	2½	3¼	3¾	4½	5	6¼	7½	8¾	10	11	12¼	13½	14¾	16	17	18¼	19¼	21½	23½	25¾	27¾
41.14	72	28	64	40	½	1	1¾	2¼	2¾	3¼	4	4½	5½	6½	7¾	8¾	9¾	10¾	11¾	13	14	15	16	17	19	21	22¾	24½
45.00	72	28	56	32	½	1	1½	2	2½	3	3½	4	5	6	7	8	9	10	11	11¾	12¾	13¾	14¾	15½	17½	19¼	21	22¾
48.00	72	24	64	40	½	1	1½	2	2½	3	3¼	3¾	4¾	5½	6½	7½	8½	9¼	10¼	11¼	12	13	13¾	14½	16½	18	19¾	21½
51.43	72	28	64	32	½	¾	1½	1¾	2¼	2¾	3	3½	4½	5¼	6	7	7¾	8¾	9½	10½	11¼	12	12¾	13¾	14¾	17	18½	20
60.00	72	24	64	32	½	¾	1¼	1½	2	2¼	2½	3	3¾	4½	5¼	6	6¾	7½	8¼	9	9½	10¼	11	11¾	13¼	14¾	16	17½

MILLING HEART-SHAPED CAMS

One method of producing heart-shaped cams is as follows:

Lay out the curve of the cam roughly, as in Fig. 19. Drill and remove the outside stock, being sure to leave sufficient stock to overcome errors in laying out. Put the cam on the nut arbor and tighten securely. If the roll of the cam is one-eighth radius, select a milling cutter having the same radius, because the roll of the cam must come to the lowest point, which it would not be able to do if a cutter of a smaller radius than that of the roll were used. It would also make a difference to the other points on the curve of the cam, which is not quite so apparent at first glance.

Selecting an Index

The next operation is to place the cam between centers on the milling machine, having the cutter in line with the vertical radius of the cam at its lowest point. Next, choose an index circle which will give a division of the cam such that the rise of each division will be in thousandths of an inch, if possible. For this cam take a circle which will give 200 divisions. As this will make 100 divisions on a side, the rise of each division will be 0.011 inch. Now raise the table to the required height, starting at the lowest point of the cam, and mill across, as in Fig. 20.

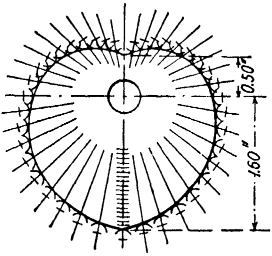


FIG. 19.—Method of Laying Out Cam

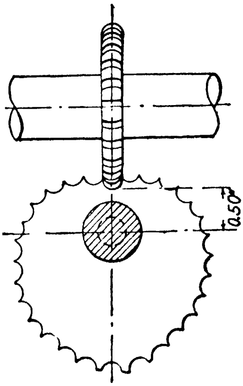


FIG. 20.—Position of Cam and Cutter When Commencing to Mill

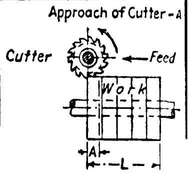
Moving the Table

For the other cuts lower the table 0.011 each time, and revolve the cam one division until the highest point of the cam is reached, then raise the table 0.011 for each division of the cam.

When the cam comes from the milling machine, there will be found to be small grooves left between the cuts. These may be easily

TABLE 7.—APPROACH OF CUTTER FOR HELICAL MILLS, KEYWAY CUTTERS, SAWS, ETC.*

Diameter of Mill	Depth of Cut, Inches											
	1/16	1/8	3/16	1/4	3/8	1/2	3/4	1	1 1/2	2	3	4
1 1/4	0.272	0.37	0.44	0.50	0.57	0.612						
1 1/2	0.299	0.41	0.49	0.56	0.65	0.71	0.75					
1 3/4	0.320	0.45	0.54	0.61	0.72	0.79	0.87					
2	0.350	0.48	0.58	0.66	0.78	0.87	0.87	1.00				
2 1/4	0.370	0.52	0.62	0.71	0.84	0.93	1.06	1.12				
2 1/2	0.390	0.54	0.66	0.75	0.89	1.00	1.15	1.22				
2 3/4	0.410	0.57	0.69	0.79	0.94	1.06	1.22	1.32				
3	0.430	0.60	0.73	0.83	0.99	1.12	1.30	1.41	1.50			
3 1/4	0.450	0.63	0.76	0.87	1.04	1.17	1.37	1.50	1.62			
3 1/2	0.460	0.65	0.79	0.91	1.08	1.22	1.44	1.58	1.73			
3 3/4	0.480	0.67	0.82	0.93	1.13	1.28	1.50	1.66	1.84			
4	0.490	0.70	0.85	0.97	1.17	1.32	1.56	1.73	1.94	2.00		
4 1/4	0.511	0.72	0.87	1.00	1.21	1.37	1.62	1.80	2.03	2.12		
4 1/2	0.530	0.74	0.90	1.03	1.24	1.41	1.67	1.87	2.12	2.24		
4 3/4	0.540	0.76	0.92	1.06	1.28	1.46	1.73	1.93	2.21	2.35		
5	0.560	0.78	0.95	1.09	1.32	1.50	1.79	2.00	2.29	2.45		
5 1/2	0.580	0.82	1.00	1.14	1.39	1.58	1.89	2.12	2.45	2.64		
6	0.610	0.86	1.04	1.20	1.45	1.66	1.98	2.24	2.60	2.83	3.00	
6 1/2	0.634	0.89	1.09	1.25	1.51	1.73	2.08	2.35	2.74	3.00	3.24	
7	0.658	0.93	1.13	1.30	1.58	1.80	2.17	2.45	2.87	3.16	3.46	
7 1/2	0.680	0.95	1.17	1.35	1.63	1.87	2.25	2.55	3.00	3.32	3.67	
8	0.710	0.99	1.21	1.39	1.69	1.94	2.33	2.65	3.12	3.46	3.87	4.00
8 1/2	0.730	1.03	1.25	1.44	1.74	2.00	2.41	2.74	3.24	3.61	4.06	4.24
9	0.750	1.05	1.28	1.48	1.80	2.06	2.49	2.83	3.36	3.74	4.24	4.47
9 1/2	0.770	1.08	1.32	1.52	1.85	2.12	2.56	2.92	3.47	3.88	4.42	4.69
10	0.790	1.11	1.35	1.56	1.90	2.18	2.63	3.00	3.57	4.00	4.58	4.90
10 1/2	0.810	1.14	1.39	1.60	1.95	2.24	2.71	3.08	3.67	4.12	4.75	5.10
11	0.830	1.17	1.42	1.64	2.00	2.29	2.77	3.16	3.77	4.24	4.89	5.29
11 1/2	0.850	1.19	1.46	1.68	2.04	2.34	2.84	3.24	3.87	4.36	5.04	5.48
12	0.860	1.22	1.49	1.72	2.09	2.40	2.91	3.32	3.97	4.47	5.19	5.65



* Follow down the first column to the diameter of cutter used. Follow across to the right to the column under the depth of cut. The figure given is the approach of the cutter. See cut.

EXAMPLE.—Two and three-fourth inches, diameter cutter; 1/4 inch, depth of cut; approach of cutter, 0.79 inch.

removed by smoothing off with a file without impairing the accuracy of the cam.

Most screw machine cams can be made in this manner, and they will be found to be more accurate than if laid out and filed to the line and also much easier to make after one has become accustomed to the method.

MILLING CAMS BY GEARING UP THE DIVIDING HEAD

By the method here shown, cams of any rise may be milled with the gears regularly furnished with the milling machine.

With the head set vertically, the lead of the cam would be the same as the lead for which the machine is geared, whereas with the head horizontal and the milling spindle also, a concentric arc, or rest, would be milled on the cam, regardless of how the machine was geared. By inclining the head and milling spindle, we can produce any lead on the cam less than that for which the machine is geared.

To find the angle for setting the index head in Fig. 21. Here the hypotenuse represents the lead of the machine and the short side the lead of the cam. Dividing the latter by the former gives the sine of the angle. With a plate cam having a rise of $\frac{1}{8}$ inch in 300 degrees we have $\frac{360}{300} \times \frac{1}{8}$ equals 0.15, or the lead we want on the cam. The slowest lead on a Brown and Sharpe machine is 0.67. Dividing 0.15 by 0.67 gives 0.224. The sine table shows 0.224 is very nearly the sine of 13 degrees. Set both the index head and the milling machine spindle at this angle so the edge of the cam will be parallel with its shaft as in Fig. 22.

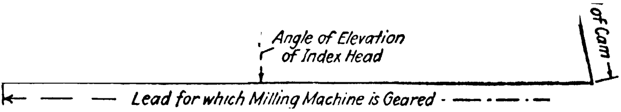

Angle of Elevation of Index Head
of Cam
Lead for which Milling Machine is Geared

FIG. 21.—Diagram for Angle of Index Head

If the cam has several lobes, gear the machine for a lead somewhat longer than the longest one on the cam. Then all the lobes can be milled with one setting of gears by altering the angle of both index head and milling spindle for each lead. If the size of the cam and the angle of the head will allow, it is best to mill on the underside of the cam. This brings the cutter and table nearer together and increases rigidity. It is also easy to see the lines on the face of the cam, and the chips fall away from the work. Feed the cutter against the work by turning the index crank. Use the handle of the machine table for return. This moves the work away from the cutter before the cam begins to turn and prevents the cutter from dragging on back stroke.

In finding angles for a set of cams, first find complete rises for all the lobes. Assign as many of these rises to any one lead as possible. This makes it possible to use the fewest number of leads.

These tables advance by cam lead differences of 0.005 up to 1 inch; then by 0.010 inch up to 1.5 inches; then by 0.025 and larger increments to 6 inches. It is believed that the simple method of figuring for all intermediate steps, as explained on pages 406 to 408, will enable the reader to make full use of this method of setting for cam milling without the necessity of making many gear changes for dividing head leads, since eight leads in the tables cover the range of cam leads or rises from 0.005 to 6 inches.

The milling machine, when used as shown in Fig. 22, will be found to be more rigid than when the head is set in the vertical position, and the cams will work more smoothly on account of the shearing action of the cutter.

One possible objection to the method here advocated is the necessity of using, in some cases, an end mill of extra length of tooth. In practice, an end mill with $\frac{7}{8}$-inch diameter and with a $3\frac{1}{2}$-inch length of tooth is not unusual; but the results in both speed and quality will be found entirely satisfactory.

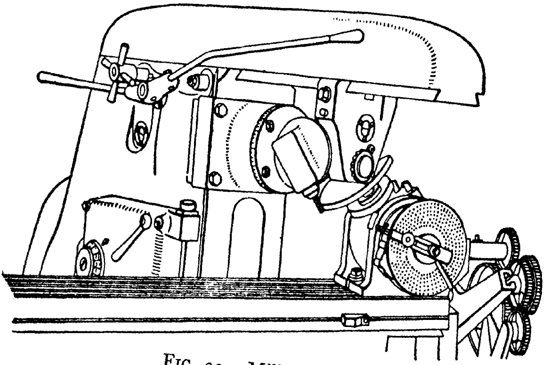


FIG. 22.—Milling Cams

TABLES OF SETTINGS FOR MILLING SCREW-MACHINE CAMS

Table 8, page 409, is for finding the angles used in milling Brown and Sharpe automatic screw machine cams. It is designed to reduce the number of gear changes to a minimum, only eight leads being given. Leads above 6 inches are omitted, since the theoretically perfect rise of a Brown and Sharpe screw machine cam is not a spiral, and with steep rises this difference becomes so pronounced that the geometrical error far exceeds any errors usual to working the rise by hand, and the hand work is probably the cheapest.

The operation of the table will be largely self-evident. The column at the left gives the cam rise for a complete revolution of the cam or the rise of lobe × 100 inches ÷ the number of hundredths in lobe. For example, we have a lobe covering eight hundredths and having a rise of 0.375 inch. Therefore, $\frac{0.375 \times 100}{8} = 4.6875$ inches or the rise for a complete revolution. The nearest rise to 4.6875 inches occurring in the table is 4.750 inches. This will usually be near enough, but if for any reason greater accuracy is required, interpolation may be resorted to.

TABLE 8.—ANGLE BETWEEN ARBOR AND TABLE

ANGLE BETWEEN ARBOR AND TABLE

Rise in a Complete Rev. of Cam	Lead of Mach. 0.670 Inch		Lead of Mach. 1.050 Inch		Lead of Mach. 1.500 Inch		Lead of Mach. 2.000 Inches		Lead of Mach. 3.000 Inches		Lead of Mach. 4.000 Inches		Lead of Mach. 5.000 Inches		Lead of Mach. 6.000 Inches	
	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.
0.005	0	26														
0.010	0	51														
0.015	1	17														
0.020	1	43														
0 025	2	08														
0 030	2	34														
0.035	3	00														
0.040	3	25														
0.045	3	51														
0.050	4	17														
0.055	4	43														
0.060	5	08														
0.065	5	34														
0.070	6	00														
0.075	6	26														
0.080	6	51														
0.085	7	17														
0.090	7	43														
0.095	8	09														
0.100	8	35														
0.105	9	01														
0.110	9	27														
0.115	9	53														
0.120	10	19														
0.125	10	45														
0.130	11	11														
0.135	11	38														
0.140	12	04														
0.145	12	30														
0.150	12	56														
0.155	13	23														
0.160	13	49														
0.165	14	15														
0.170	14	42														
0.175	15	08														
0.180	15	35														
0.185	16	02														
0.190	16	28														
0.195	16	58														
0.200	17	22														
0.205	17	49														
0.210	18	16														
0.215	18	43														
0.220	19	10														
0.225	19	37														
0.230	20	05														
0.235	20	32														
0.240	20	59														
0.245	21	27														
0.250	21	55														
0.255	22	22														
0.260	22	50	14	20												
0.265	23	18	14	37												
0.270	23	46	14	54												
0.275	24	14	15	11												

TABLE 8.—ANGLE BETWEEN ARBOR AND TABLE—*Continued*

Rise in a Complete Rev. of Cam	Lead of Mach. 0.670 Inch		Lead of Mach. 1.050 Inch		Lead of Mach. 1.500 Inch		Lead of Mach. 2.000 Inches		Lead of Mach. 3.000 Inches		Lead of Mach. 4.000 Inches		Lead of Mach. 5.000 Inches		Lead of Mach. 6.000 Inches	
	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.
0.280	24	42	15	28												
0.285	25	10	15	45												
0.290	25	39	16	02												
0.295	26	07	16	19												
0.300	26	36	16	36												
0.305	27	05	16	53												
0.310	27	34	17	10												
0.315	28	03	17	27												
0.320	28	32	17	45												
0.325	29	01	18	02												
0.330	29	30	18	19												
0.335	30	00	18	36												
0.340	30	30	18	54												
0.345	30	59	19	11												
0.350	31	30	19	28												
0.355	32	00	19	46												
0.360	32	30	20	04												
0.365	33	01	20	21												
0.370	33	31	20	38												
0.375	34	02	20	55												
0.380	34	33	21	13												
0.385	35	04	21	31												
0.390	35	36	21	48												
0.395	36	07	22	06												
0.400	36	39	22	24												
0.405	37	12	22	41												
0.410	37	44	22	59												
0.415	38	16	23	17												
0.420	38	49	23	35												
0.425	39	22	23	53												
0.430	39	55	24	11												
0.435	40	29	24	28												
0.440	41	03	24	46												
0.445	41	37	25	05												
0.450	42	12	25	23												
0.455	42	47	25	41												
0.460	43	22	25	59												
0.465	43	57	26	17												
0.470	44	32	26	35												
0.475	45	09	26	54												
0.480	45	46	27	12												
0.485	46	23	27	31												
0.490	47	00	27	49												
0.495	47	38	28	07												
0.500	48	16	28	26	19	28										
0.505	48	55	28	45	19	40										
0.510	49	34	29	04	19	53										
0.515	50	14	29	23	20	05										
0.520	50	55	29	41	20	17										
0.525	51	35	30	00	20	29										
0.530	52	27	30	19	20	41										
0.535	52	59	30	39	20	54										
0.540	53	43	30	57	21	06										
0.545	54	26	31	16	21	18										
0.550	55	11	31	35	21	31										

TABLE 8.—ANGLE BETWEEN ARBOR AND TABLE.—*Continued*

Rise in a Complete Rev. of Cam	Lead of Mach. 0.670 Inch		Lead of Mach. 1.050 Inch		Lead of Mach. 1.500 Inch		Lead of Mach. 2.000 Inches		Lead of Mach. 3.000 Inches		Lead of Mach. 4.000 Inches		Lead of Mach. 5.000 Inches		Lead of Mach. 6.000 Inches	
	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.
0.555	55	50	31	55	21	43										
0.560	56	42	32	14	21	55										
0.565	57	30	32	33	22	08										
0.570	58	18	32	53	22	20										
0.575	59	07	33	12	22	33										
0.580	59	58	33	32	22	45										
0.585	60	50	33	52	22	57										
0.590	61	43	34	12	23	10										
0.595	62	38	34	31	23	22										
0.600	63	35	34	51	23	35	17	27								
0.605	64	34	35	11	23	47	17	37								
0.610	65	33	35	31	24	00	17	46								
0.615	66	41	35	51	24	13	17	54								
0.620	67	54	36	12	24	25	18	04								
0.625	68	53	36	31	24	37	18	13								
0.630	70	06	36	52	24	50	18	22								
0.635	71	24	37	13	25	03	18	31								
0.640	72	48	37	33	25	15	18	40								
0.645	74	17	37	55	25	28	18	49								
0.650	75	58	38	15	25	40	18	58								
0.655	77	51	38	36	25	53	19	07								
0.660	80	06	38	57	26	06	19	16								
0.665	83	00	39	18	26	19	19	25								
0.670	90	00	39	39	26	32	19	34								
0.675			40	00	26	45	19	43								
0.680			40	22	26	57	19	53								
0.685			40	43	27	10	20	02								
0.690			41	05	27	23	20	11								
0.695			41	27	27	36	20	20								
0.700			41	49	27	49	20	29								
0.705			42	11	28	02	20	38								
0.710			42	33	28	15	20	48								
0.715			42	55	28	27	20	57								
0.720			43	17	28	40	20	06								
0.725			43	40	28	53	21	15								
0.730			44	03	29	07	21	24								
0.735			44	26	29	21	21	34								
0.740			44	49	29	34	21	43								
0.745			45	12	29	47	21	52								
0.750			45	35	30	00	22	02								
0.755			45	58	30	13	22	11								
0.760			46	22	30	27	22	20								
0.765			46	46	30	40	22	29								
0.770			47	10	30	53	22	39								
0.775			47	34	31	06	22	48								
0.780			47	59	31	20	22	57								
0.785			48	23	31	34	23	07								
0.790			48	48	31	47	23	16								
0.795			49	13	32	00	23	25								
0.800			49	38	32	14	23	35								
0.805			50	03	32	27	23	44								
0.810			50	29	32	41	23	54								
0.815			50	55	32	55	24	03								
0.820			51	21	33	08	24	12								
0.825			51	47	33	22	24	22								

TABLE 8.—ANGLE BETWEEN ARBOR AND TABLE—*Continued*

Rise in a Complete Rev. of Cam	Lead of Mach. 0.670 Inch		Lead of Mach. 1.050 Inch		Lead of Mach. 1.500 Inch		Lead of Mach. 2.000 Inches		Lead of Mach. 3.000 Inches		Lead of Mach. 4.000 Inches		Lead of Mach. 5.000 Inches		Lead of Mach. 6.000 Inches	
	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.
0.830			52	14	33	36	24	31								
0.835			52	41	33	49	24	41								
0.840			53	08	34	03	24	50								
0.845			53	36	34	17	25	00								
0.850			54	03	34	31	25	09								
0.855			54	31	34	45	25	19								
0.860			55	00	34	59	25	28								
0.865			55	28	35	13	25	38								
0.870			55	57	35	27	25	47								
0.875			56	26	35	41	25	57								
0.880			56	56	35	55	26	06								
0.885			57	27	36	10	26	16								
0.890			57	58	36	24	26	25								
0.895			58	29	36	38	26	35								
0.900			59	00	36	52	26	45								
0.905			59	32	37	07	26	54								
0.910			60	06	37	21	27	04								
0.915			60	38	37	35	27	13								
0.920			61	11	37	50	27	23								
0.925			61	46	38	04	27	33								
0.930			62	20	38	19	27	43								
0.935			62	57	38	33	27	52								
0.940			63	33	38	48	28	02								
0.945			64	11	39	03	28	12								
0.950			64	49	39	18	28	22								
0 955			65	26	39	33	28	31								
0 960			66	06	39	47	28	41								
0.965			66	48	40	02	28	51								
0.970			67	30	40	17	29	01								
0.975			68	13	40	32	29	11								
0.980			68	54	40	47	29	20								
0.985			69	45	41	01	29	30								
0.990			70	32	41	17	29	40								
0.995			71	23	41	33	29	50								
1.000			72	15	41	49	30	00	19	28						
1.010			74	08	42	20	30	20	19	40						
1.020			76	16	42	50	30	40	19	53						
1.030			78	48	43	23	31	00	20	05						
1.040			82	05	43	54	31	20	20	17						
1.050			90	00	44	27	31	40	20	29						
1.060					44	57	32	00	20	41						
1.070					45	30	32	20	20	54						
1.080					46	04	32	41	21	06						
1.090					46	36	33	01	21	18						
1.100					47	10	33	22	21	30						
1.110					47	44	33	43	21	43						
1.120					48	18	34	03	21	55						
1.130					48	53	34	24	22	07						
1.140					49	28	34	45	22	20						
1.150					50	03	35	06	22	33						
1.160					50	39	35	27	22	45						
1.170					51	16	35	48	22	58						
1.180					51	53	36	09	23	10						
1.190					52	30	36	31	23	22						
1.200					53	08	36	52	23	35						

TABLE 8.—ANGLE BETWEEN ARBOR AND TABLE.—*Continued*

Rise in a Complete Rev. of Cam	Lead of Mach. 0.670 Inch		Lead of Mach. 1.050 Inch		Lead of Mach. 1.500 Inch		Lead of Mach. 2.000 Inches		Lead of Mach. 3.000 Inches		Lead of Mach. 4.000 Inches		Lead of Mach. 5.000 Inches		Lead of Mach. 6.000 Inches	
	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.
1.210					53	46	37	14	23	47						
1.220					54	25	37	35	23	59						
1.230					55	05	37	57	24	12						
1.240					55	45	38	19	24	25						
1.250					56	26	38	41	24	37	18	13				
1.260					57	08	39	03	24	50	18	22				
1.270					57	51	39	25	25	03	18	31				
1.280					58	34	39	48	25	15	18	40				
1.290					59	19	40	09	25	28	18	49				
1.300					60	04	40	32	25	41	18	58				
1.310					60	51	40	55	25	53	19	07				
1.320					61	38	41	18	26	06	19	16				
1.330					62	28	41	41	26	19	19	25				
1.340					63	17	42	04	26	32	19	34				
1.350					64	10	42	27	26	45	19	43				
1.360					65	03	42	50	26	57	19	53				
1.370					65	59	43	14	27	10	20	02				
1.380					66	56	43	38	27	23	20	11				
1.390					67	55	44	02	27	36	20	20				
1.400					68	49	44	25	27	49	20	29				
1.410					70	03	44	50	28	02	20	39				
1.420					71	12	45	14	28	15	20	48				
1.430					72	26	45	39	28	28	20	57				
1.440					73	45	46	03	28	41	21	06				
1.450					75	09	46	28	28	54	21	15				
1.460					76	45	46	53	29	07	21	24				
1.470					78	31	47	18	29	20	21	34				
1.480					80	38	47	44	29	33	21	43				
1.490					83	23	48	10	29	46	21	52				
1.500					90	00	48	36	30	00	22	02				
1.525							49	41	30	32	22	24				
1.550							50	48	31	06	22	48				
1.575							51	57	31	40	23	11				
1.600							53	09	32	14	23	35	18	40		
1.625							54	23	32	48	23	58	18	58		
1.650							55	39	33	22	24	21	19	16		
1.675							56	52	33	56	24	45	19	34		
1.700							58	12	34	31	25	09	19	52		
1.725							59	36	35	06	25	33	20	11		
1.750							61	03	35	41	25	57	20	29		
1.775							62	34	36	16	26	21	20	48		
1.800							64	10	36	52	26	45	21	06		
1.825							65	51	37	28	27	09	21	24		
1.850							67	40	38	04	27	33	21	43		
1.875							69	38	38	41	27	57	22	02		
1.900							71	49	39	16	28	21	22	20		
1.925							74	16	39	55	28	46	22	39		
1.950							77	10	40	33	29	10	22	57		
1.975							80	56	41	11	29	35	23	16		
2.000							90	00	41	49	30	00	23	35	19	28
2.100									44	26	31	40	24	50	20	28
2.200									47	10	33	22	26	06	21	30
2.300									50	03	35	06	27	23	22	32
2.400									53	08	36	52	28	41	23	35

TABLE 8.—ANGLE BETWEEN ARBOR AND TABLE—*Continued*

Rise in a Complete Rev. of Cam	Lead of Mach. 0.670 Inch		Lead of Mach. 1.050 Inch		Lead of Mach. 1.500 Inch		Lead of Mach. 2.000 Inches		Lead of Mach. 3.000 Inches		Lead of Mach. 4.000 Inches		Lead of Mach. 5.000 Inches		Lead of Mach. 6.000 Inches	
	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.	Degs.	Min.
2.500									56	24	38	41	30	00	24	37
2.600									60	04	40	32	31	20	25	41
2.700									64	09	42	27	32	41	26	45
2.800									68	58	44	25	34	03	27	49
2.900									75	09	46	28	35	27	28	53
3.000									90	00	48	36	36	52	30	00
3.100											50	48	38	19	31	08
3.200											53	08	39	47	32	22
3.300											55	35	41	18	33	22
3.400											58	13	42	51	34	31
3.500											61	03	44	26	35	41
3.600											64	09	46	03	36	52
3.700											67	40	47	44	38	04
3.800											71	49	49	28	39	18
3.900											77	10	51	16	40	33
4.000											90	00	53	07	41	49
4.250													58	12	45	09
4.500													64	10	48	36
4.750													71	49	52	20
5.000													90	00	56	26
5.250															61	03
5.500															66	26
5.750															73	24
6.000															90	00

Other Tables for Milling Cams

The following tables computed by the Cincinnati Milling Machine Co. will be also found very useful.

These tables give all the information necessary and it only remains for the milling machine operator to select the lead of the desired cam from the tables and set up for the corresponding change gears and angles.

In setting the vertical milling attachment read the angle direct from the dial. Example: if the angle given in the table is 39½ degrees, set the spindle 39½ degrees from its vertical position.

In setting the dividing head, subtract the angle in the table from 90 degrees. The difference represents the angle to which the dividing head spindle must be raised from the horizontal position.

Example: The angle given in the table is 39½ degrees. 90 degrees minus 39½ degrees equals 50½ degrees.

Set the dividing head spindle 50½ degrees up from the horizontal position. This angle is read direct from the dial. The setup is shown in Fig. 22.

The tables may of course be used in connection with the cutting of any other similar cams.

TABLE 9.—GEARS FOR MILLING CAMS

Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle	Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle	Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle
.600	24	86	24	100	26½	.650	24	86	24	100	14	.700	24	72	24	100	29
.601	24	86	24	100	26	.651	24	86	28	100	33½	.701	24	72	24	86	41
.602	24	86	24	100	26	.652	24	86	24	100	13½	.702	24	86	28	100	26
.603	24	86	28	100	39½	.653	24	86	32	100	43	.703	24	72	24	100	28½
.604	24	72	24	100	41	.654	24	86	24	100	12½	.704	24	86	32	100	38
.605	24	86	24	100	25½	.655	24	86	24	100	12	.705	24	86	28	100	25½
.606	24	86	28	100	39	.656	24	86	24	100	11½	.706	24	72	24	100	28
.607	24	86	24	100	25	.657	24	86	24	100	11	.707	24	72	24	86	40½
.608	24	72	24	100	40½	.658	24	86	32	100	42½	.708	24	86	28	100	25
.609	24	86	24	100	24½	.659	24	72	24	100	34½	.709	24	72	28	100	40½
.610	24	86	24	100	24½	.660	24	86	24	100	10	.710	24	72	24	100	27½
.611	24	86	28	100	38½	.661	24	86	28	100	32	.711	24	86	28	100	24½
.612	24	86	24	100	24	.662	24	86	28	100	32	.712	24	72	24	86	40
.613	24	72	24	100	40	.663	24	72	24	100	34	.713	24	72	24	100	27
.614	24	86	24	100	23½	.664	24	86	32	100	42	.714	24	64	24	100	37½
.615	24	86	28	100	38	.665	24	72	28	100	44½	.715	24	72	28	100	40
.616	24	86	24	100	23	.666	24	86	28	100	31½	.716	24	86	28	100	23½
.617	24	72	24	100	39½	.667	24	72	24	100	33½	.717	24	72	24	86	39½
.618	24	72	24	100	39½	.668	24	64	24	100	42	.718	24	86	32	100	36½
.619	24	86	24	100	22½	.669	24	72	24	86	44	.719	24	86	28	100	23
.620	24	86	28	100	37½	.670	24	86	28	100	31	.720	24	72	28	100	39½
.621	24	86	24	100	22	.671	24	72	24	100	33	.721	24	86	28	100	22½
.622	24	72	24	100	39	.672	24	86	28	100	30½	.722	24	72	24	100	25½
.623	24	86	24	100	21½	.673	24	86	28	100	30½	.723	24	64	24	100	36½
.624	24	86	28	100	37	.674	24	64	24	100	41½	.724	24	86	28	100	22
.625	24	86	24	100	21	.675	24	72	24	100	32½	.725	24	72	24	100	25
.626	24	86	32	100	45½	.676	24	86	28	100	30	.726	24	86	28	100	21½
.627	24	86	24	100	20½	.677	24	72	28	100	43½	.727	24	86	32	100	35½
.628	24	86	28	100	36½	.678	24	72	24	100	32	.728	24	72	24	100	24½
.629	24	86	24	100	20	.679	24	86	32	100	40½	.729	24	86	28	100	21
.630	24	72	24	100	38	.680	24	72	24	86	43	.730	24	72	28	100	38½
.631	24	86	32	100	45	.681	24	72	24	100	31½	.731	24	72	24	100	24
.632	24	86	28	100	36	.682	24	72	28	100	43	.732	24	86	28	100	20½
.633	24	86	24	100	19	.683	24	86	28	100	29	.733	24	72	24	86	38
.634	24	72	24	100	37½	.684	24	86	32	100	40	.734	24	86	28	100	20
.635	24	86	24	100	18½	.685	24	72	24	86	42½	.735	24	72	28	100	38
.636	24	86	28	100	35½	.686	24	86	28	100	28½	.736	24	86	28	100	19½
.637	24	86	32	100	44½	.687	24	72	28	100	42½	.737	24	64	24	100	35
.638	24	72	24	100	37	.688	24	72	28	100	42½	.738	24	72	24	86	37½
.639	24	86	24	100	17½	.689	24	86	32	100	39½	.739	24	72	24	100	22½
.640	24	86	28	100	35	.690	24	86	28	100	28	.740	24	72	28	100	37½
.641	24	86	24	100	17	.691	24	72	24	86	42	.741	24	86	28	100	18½
.642	24	86	32	100	44	.692	24	86	28	100	27½	.742	24	72	24	100	22
.643	24	86	28	100	34½	.693	24	72	28	100	42	.743	24	86	28	100	18
.644	24	86	24	100	16	.694	24	86	32	100	39	.744	24	72	24	100	21½
.645	24	86	24	100	15½	.695	24	64	24	100	39½	.745	24	72	28	100	37
.646	24	86	24	100	15½	.696	24	86	28	100	27	.746	24	64	24	100	34
.647	24	86	24	100	15	.697	24	72	24	86	41½	.747	24	86	28	100	17
.648	24	86	32	100	43½	.698	24	72	28	100	41½	.748	24	72	24	86	36½
.649	24	86	24	100	14½	.699	24	86	32	100	38½	.749	24	86	28	100	16½

TABLE 9.—GEARS FOR MILLING CAMS.—*Continued*

Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle	Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle	Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle
·750	24	72	28	100	36½	.800	24	72	28	100	31	.850	24	72	24	86	24
·751	24	86	28	100	16	.801	24	72	24	86	30½	.852	24	64	24	100	19
·752	24	72	24	100	20	.802	24	64	24	86	40	.851	24	72	28	100	24
·753	24	86	32	100	32½	.803	24	86	32	100	26	.853	24	72	24	86	23½
·754	24	72	24	100	19½	.804	28	86	32	100	39½	.854	24	86	32	100	17
·755	24	72	28	100	36	.805	24	72	32	100	41	.855	24	64	28	100	35½
·756	24	86	28	100	14½	.806	24	86	32	100	25½	.856	24	86	32	100	16½
·757	24	72	24	86	35½	.807	24	64	24	86	39½	.857	24	64	24	86	35
·758	24	86	28	100	14	.808	24	72	28	100	30	.858	24	64	24	100	17½
·759	24	64	24	100	32½	.809	24	64	24	100	26	.859	24	72	24	86	22½
·760	24	72	28	100	35½	.810	28	86	32	100	39	.860	24	64	28	100	35
·761	24	86	28	100	13	.811	24	72	32	100	40½	.861	24	72	28	86	37½
·762	24	72	24	86	35	.812	24	72	28	100	29½	.862	24	72	28	100	22½
·763	24	72	24	100	17½	.813	24	72	24	86	29	.863	24	64	24	100	16½
·764	24	86	28	100	12	.814	24	64	24	86	39	.864	28	86	32	100	34
·765	24	72	24	100	17	.815	28	86	32	100	38½	.865	24	64	24	100	16
·766	24	72	24	86	34½	.816	24	72	28	100	29	.866	24	86	32	100	14
·767	24	72	24	100	16½	.817	24	72	24	86	28½	.867	24	64	24	100	15½
·768	24	86	28	100	10½	.818	24	72	28	86	41	.868	24	72	28	100	21½
·769	24	86	28	100	10	.819	24	86	32	100	23½	.869	24	64	24	100	15
·770	24	86	32	100	30½	.820	24	72	28	100	28½	.870	24	86	32	100	13
·771	24	72	24	86	34	.821	24	72	24	86	28	.871	24	64	24	100	14½
·772	24	72	24	100	15	.822	24	86	32	100	23	.872	24	86	32	100	12½
·773	24	86	32	100	30	.823	24	72	32	100	39½	.873	24	64	24	100	14
·774	24	72	24	100	14½	.824	24	72	28	100	28	.874	24	72	24	86	20
·775	24	64	24	100	30½	.825	24	72	24	86	27½	.875	24	86	32	100	11½
·776	24	72	24	100	14	.826	28	86	32	100	37½	.876	24	64	28	100	33½
·777	24	86	32	100	29½	.827	24	72	28	100	27½	.877	24	64	24	100	13
·778	24	72	28	100	33½	.828	24	86	32	100	22	.878	24	86	32	100	10½
·779	24	72	24	100	13	.829	24	86	40	100	42	.879	24	64	24	100	12½
·780	24	72	24	86	33	.830	24	64	24	86	37½	.880	24	64	24	100	12
·781	24	72	24	100	12½	.831	24	72	28	86	40	.881	24	64	28	100	33
·782	24	72	28	100	33	.832	24	72	24	86	26½	.882	24	64	24	100	11½
·783	24	64	24	100	29½	.833	24	56	24	100	36	.883	24	64	24	86	32½
·784	24	72	24	100	11½	.834	24	86	32	100	21	.884	28	86	32	100	32
·785	24	86	32	100	28½	.835	24	72	32	100	38½	.885	24	64	24	100	10½
·786	28	86	32	100	41	.836	24	72	24	86	26	.886	24	64	24	100	10
·787	24	64	24	100	29	.837	24	72	28	86	39½	.887	24	72	24	86	17½
·788	24	72	24	100	10	.838	24	56	24	100	35½	.888	24	64	24	86	32
·789	24	72	24	86	32	.839	24	86	32	100	20	.889	24	72	24	86	17
·790	24	64	24	86	41	.840	24	64	24	100	21	.890	24	72	28	100	17½
·791	24	64	24	100	28½	.841	24	72	32	100	38	.891	24	56	24	100	30
·792	24	86	32	100	27½	.842	24	86	32	100	19½	.892	24	72	24	86	16½
·793	24	72	24	86	31½	.843	24	72	28	86	39	.893	28	86	32	100	31
·794	24	72	28	86	43	.844	24	86	32	100	19	.894	24	72	24	86	16
·795	24	72	28	100	31½	.845	24	72	28	100	25	.895	24	64	28	100	31½
·796	24	64	24	86	40½	.846	24	64	24	100	20	.896	24	72	24	86	15½
·797	24	72	24	86	31	.847	24	86	32	100	18½	.897	24	72	28	100	16
·798	28	86	32	100	40	.848	24	64	24	100	19½	.898	24	72	24	86	15
·799	24	72	32	100	41½	.849	24	86	32	100	18	.899	24	72	28	100	15½

TABLE 9.—GEARS FOR MILLING CAMS.—*Continued*

Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle	Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle	Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle
.900	24	56	24	100	29	.950	24	72	32	86	40	1.000	24	86	44	100	35½
.901	24	72	28	100	15	.951	24	56	24	100	22½	1.001	24	56	24	100	13½
.902	24	72	24	86	14	.952	28	86	32	100	24	1.002	28	86	32	100	16
.903	24	72	28	100	14½	.953	24	64	24	86	24½	1.003	24	56	24	100	13
.904	24	72	24	86	13½	.954	24	56	24	100	22	1.004	28	86	32	100	15½
.905	24	72	28	100	14	.955	24	72	32	100	26½	1.005	24	56	24	100	12½
.906	24	72	24	86	13	.956	24	64	28	86	38½	1.006	24	56	24	100	12
.907	24	72	28	100	13½	.957	24	56	24	100	21½	1.007	24	64	24	86	16
.908	24	72	24	86	12½	.958	24	72	28	86	28	1.008	24	56	24	100	11½
.909	24	72	28	100	13	.959	24	72	32	100	26	1.009	28	86	32	100	14½
.910	24	72	32	100	31½	.960	24	64	24	86	23½	1.010	24	56	24	100	11
.911	24	72	28	100	12½	.961	24	86	44	100	38½	1.011	28	86	32	100	14
.912	24	72	28	100	12	.962	24	72	28	86	27½	1.012	24	56	24	100	10½
.913	24	72	24	86	11	.963	28	86	32	100	22½	1.013	24	56	24	100	10
.914	24	72	28	100	11½	.964	24	56	24	100	20½	1.014	24	64	24	86	14½
.915	24	72	32	100	31	.965	24	64	32	100	36½	1.015	28	86	32	100	13
.916	24	72	24	86	10	.966	28	86	32	100	22	1.016	24	64	24	86	14
.917	24	72	28	100	10½	.967	24	56	24	100	20	1.017	28	86	32	100	12½
.918	24	64	28	100	29	.968	24	56	24	86	36	1.018	24	64	24	86	13½
.919	24	72	28	100	10	.969	24	64	28	86	37½	1.019	28	86	32	100	12
.920	28	86	32	100	28	.970	24	56	24	100	19½	1.020	24	64	24	86	13
.921	24	56	24	100	26½	.971	24	72	28	86	26½	1.021	28	86	32	100	11½
.922	24	64	28	86	41	.972	86	44	32	64	6	1.022	24	64	24	86	12½
.923	24	64	28	100	28½	.973	24	56	24	100	19	1.023	28	86	32	100	11
.924	28	86	32	100	27½	.974	24	64	24	86	21½	1.024	24	64	24	86	12
.925	24	56	24	100	26	.975	24	72	32	100	24	1.025	24	64	28	100	12½
.926	24	64	32	100	39½	.976	28	86	32	100	20½	1.026	24	64	24	86	11½
.927	24	64	28	100	28	.977	24	64	28	100	21½	1.027	24	64	28	100	12
.928	24	64	28	86	40½	.978	24	56	24	100	18	1.028	24	64	24	86	11
.929	24	56	24	100	25½	.979	28	86	32	100	20	1.029	24	64	28	100	11½
.930	24	72	28	86	31	.980	24	64	28	100	21	1.030	24	64	24	86	10½
.931	24	64	28	100	27½	.981	24	64	24	86	20½	1.031	24	64	28	100	11
.932	28	72	32	100	41½	.982	28	86	32	100	19½	1.032	24	64	28	100	10½
.933	24	64	24	86	27	.983	24	72	28	86	25	1.033	24	72	32	100	14½
.934	24	86	44	100	40½	.984	24	56	24	100	17	1.034	24	64	28	100	10
.935	24	72	28	86	30½	.985	28	86	32	100	19	1.035	24	72	32	100	14
.936	24	56	24	100	24½	.986	24	72	32	100	22½	1.036	24	56	24	86	30
.937	24	64	24	86	26½	.987	24	64	24	86	19½	1.037	24	72	32	100	13½
.938	24	72	32	100	28½	.988	28	86	32	100	18½	1.038	24	72	28	86	17
.939	24	64	32	100	38½	.989	24	56	24	100	16	1.039	24	64	32	100	30
.940	24	56	24	100	24	.990	24	64	24	86	19	1.040	24	72	32	100	13
.941	24	64	24	86	26	.991	28	86	32	100	18	1.041	24	56	24	86	29½
.942	24	72	32	100	28	.992	24	56	24	100	15½	1.042	24	72	32	100	12½
.943	24	72	32	86	40½	.993	24	64	24	86	18½	1.043	24	72	28	86	16
.944	24	56	24	100	23½	.994	24	56	24	100	15	1.044	24	72	32	100	12
.945	24	64	24	86	25½	.995	24	72	28	86	23½	1.045	24	86	40	100	20½
.946	24	72	32	100	27½	.996	24	56	24	100	14½	1.046	24	72	32	100	11½
.947	24	56	24	100	23	.997	24	56	24	86	33½	1.047	24	72	32	100	11
.948	28	86	32	100	24½	.998	24	56	24	100	14	1.048	24	72	28	86	15
.949	24	64	24	86	25	.999	28	86	32	100	16½	1.049	24	72	32	100	10½

TABLE 9.—GEARS FOR MILLING CAMS.—*Continued*

Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle	Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle	Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle
1.050	24	72	28	86	14½	1.150	24	56	24	86	16	1.250	24	64	28	72	31
1.052	24	86	40	100	19½	1.152	28	86	44	100	36½	1.252	28	86	40	100	16
1.054	24	72	28	86	14	1.154	24	64	28	86	19	1.254	24	64	32	86	26
1.056	24	56	24	86	28	1.156	24	64	32	100	15½	1.256	24	64	28	72	30½
1.058	24	86	40	100	18½	1.158	24	56	24	86	14½	1.258	28	86	40	100	15
1.060	28	86	40	100	35½	1.160	24	56	24	86	14	1.260	28	86	40	100	14½
1.062	24	72	28	86	12	1.162	24	64	32	100	14½	1.262	32	56	24	100	23
1.064	24	86	40	100	17½	1.164	24	64	32	100	14	1.264	24	72	40	100	18½
1.066	24	56	24	86	27	1.166	24	72	40	100	29	1.266	28	86	40	100	13½
1.068	24	64	28	86	29	1.168	24	56	24	86	12½	1.268	24	72	40	100	18
1.070	24	86	40	100	16½	1.170	24	56	24	86	12	1.270	24	72	44	100	30
1.072	28	72	32	100	30½	1.172	24	56	24	86	11½	1.272	28	72	32	86	28½
1.074	24	64	32	100	26½	1.174	24	56	24	86	11	1.274	28	86	40	100	12
1.076	24	64	32	86	39½	1.176	24	56	24	86	10½	1.276	28	86	40	100	11½
1.078	24	86	40	100	15	1.178	24	56	24	86	10	1.278	28	86	40	100	11
1.080	24	86	40	100	14½	1.180	24	64	32	100	10½	1.280	28	86	40	100	10½
1.082	28	86	44	100	41	1.182	24	64	32	100	10	1.282	28	86	40	100	10
1.084	24	56	24	86	25	1.184	24	64	32	100	9½	1.284	24	72	40	100	15½
1.086	28	86	40	100	33½	1.186	24	86	44	100	15	1.286	40	64	24	100	31
1.088	24	56	24	86	24½	1.188	24	72	40	100	27	1.288	24	72	40	100	15
1.090	24	72	32	86	28½	1.190	24	64	28	86	13	1.290	24	72	40	100	14½
1.092	24	86	40	100	12	1.192	24	64	28	86	12½	1.292	32	56	24	100	19½
1.094	24	86	40	100	11½	1.194	24	64	28	86	12	1.294	24	86	48	100	15
1.096	24	86	40	100	11	1.196	28	72	32	100	16	1.296	24	72	40	100	13½
1.098	28	72	32	100	28	1.198	24	72	32	86	15	1.298	24	64	32	86	21½
1.100	28	72	32	86	40½	1.200	24	72	32	86	14½	1.300	24	86	48	100	14
1.102	24	64	28	86	25½	1.202	24	64	28	86	10	1.302	24	64	32	86	21
1.104	24	86	44	100	26	1.204	28	72	32	100	14½	1.304	24	72	40	100	12
1.106	40	64	24	100	42½	1.206	24	72	32	86	13½	1.306	24	72	40	100	11½
1.108	24	86	44	100	25½	1.208	24	72	32	86	13	1.308	24	72	40	100	11
1.110	24	72	32	86	26½	1.210	28	72	32	100	13½	1.310	24	64	28	72	26
1.112	24	72	40	100	33½	1.212	28	72	32	100	13	1.312	40	64	24	100	29
1.114	24	64	32	86	37	1.214	24	86	48	100	25	1.314	28	86	44	100	23½
1.116	24	56	24	86	21	1.216	32	56	24	100	27½	1.316	28	64	32	100	20
1.118	28	72	32	100	26	1.218	24	72	40	100	24	1.318	24	86	48	100	10½
1.120	24	56	24	86	20½	1.220	28	86	40	100	20½	1.320	24	86	48	100	10
1.122	24	86	44	100	24	1.222	24	72	40	100	23½	1.322	28	72	32	86	24
1.124	24	56	24	86	20	1.224	28	86	40	100	20	1.324	32	56	24	100	15
1.126	24	86	44	100	23½	1.226	24	72	48	100	40	1.326	32	86	40	100	27
1.128	24	64	32	100	20	1.228	28	86	44	100	31	1.328	28	64	32	100	18½
1.130	24	72	40	100	32	1.230	28	64	32	100	28½	1.330	32	56	24	100	14
1.132	24	64	28	86	22	1.232	24	72	40	100	22½	1.332	28	64	32	100	18
1.134	24	56	24	86	18½	1.234	24	86	48	100	23	1.334	24	64	32	86	17
1.136	24	64	28	86	21½	1.236	24	72	40	100	22	1.336	32	56	24	100	13
1.138	24	64	32	100	18½	1.238	28	86	40	100	18	1.338	32	56	24	100	12½
1.140	24	64	28	86	21	1.240	24	72	40	100	21½	1.340	24	72	44	100	24
1.142	24	64	32	86	35	1.242	28	86	40	100	17½	1.342	28	64	32	100	16½
1.144	24	56	24	86	17	1.244	24	72	40	100	21	1.344	24	64	32	86	15½
1.146	24	86	44	100	21	1.246	32	72	40	100	45½	1.346	32	56	24	100	11
1.148	24	64	32	100	17	1.248	28	86	40	100	16½	1.348	32	56	24	100	10½

TABLE 9.—GEARS FOR MILLING CAMS.—*Continued*

Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle	Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle	Lead	Gear no Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle.
1.350	32	56	24	100	10	1.450	32	86	40	100	13	1.550	44	64	24	100	20
1.352	28	64	32	100	15	1.452	40	64	24	100	14½	1.552	24	72	48	100	14
1.354	24	64	32	86	14	1.454	28	86	48	100	21½	1.554	24	64	40	86	27
1.356	24	64	32	86	13½	1.456	24	72	40	86	20	1.556	24	64	32	72	21
1.358	28	64	32	100	14	1.458	32	86	40	100	11½	1.558	24	72	44	86	24
1.360	28	72	32	86	20	1.460	24	44	32	86	44	1.560	44	64	24	100	19
1.362	24	64	32	86	12½	1.462	40	64	24	100	13	1.562	24	72	48	100	12½
1.364	24	64	32	86	12	1.464	40	64	24	100	12½	1.564	24	72	44	86	23½
1.366	24	64	28	72	20½	1.466	24	72	40	86	19	1.566	32	86	44	100	17
1.368	28	72	32	86	19	1.468	28	64	40	100	33	1.568	24	72	48	100	11½
1.370	28	86	44	100	17	1.470	40	64	24	100	11½	1.570	32	72	40	100	28
1.372	24	64	32	86	10½	1.472	40	64	24	100	11	1.572	28	64	32	86	15
1.374	24	64	32	86	10	1.474	24	72	40	86	18	1.574	32	86	44	100	16
1.376	28	72	32	86	18	1.476	28	72	40	100	18½	1.576	24	72	48	100	10
1.378	28	86	44	100	16	1.478	24	72	40	86	17½	1.578	44	64	24	100	17
1.380	28	72	32	86	17½	1.480	28	72	40	100	18	1.580	28	64	32	86	14
1.382	24	64	32	72	34	1.482	24	72	40	86	17	1.582	44	64	24	100	16½
1.384	28	86	44	100	15	1.484	28	72	40	100	17½	1.584	40	56	24	100	22½
1.386	40	64	24	100	22½	1.486	24	72	40	86	16½	1.586	28	64	32	86	13
1.388	28	64	32	86	31½	1.488	28	72	40	100	17	1.588	32	86	44	100	14
1.390	28	86	44	100	14	1.490	24	72	40	86	16	1.590	44	64	24	100	15½
1.392	44	64	24	100	32½	1.492	28	72	40	100	16½	1.592	28	64	32	86	12
1.394	28	72	32	86	15½	1.494	24	72	40	86	15½	1.594	44	64	24	100	15
1.396	28	86	44	100	13	1.496	28	72	40	100	16	1.596	28	64	44	100	34
1.398	28	72	32	86	15	1.498	32	64	40	100	41½	1.598	28	64	32	86	11
1.400	40	64	24	100	21	1.500	28	64	40	100	31	1.600	44	56	24	100	21
1.402	28	86	44	100	12	1.502	28	86	48	100	16	1.602	24	64	32	72	16
1.404	28	72	32	86	14	1.504	24	72	40	86	14	1.604	32	86	44	100	11½
1.406	28	86	44	100	11	1.506	28	72	40	100	14½	1.606	24	64	32	72	15½
1.408	24	64	28	72	15	1.508	24	72	48	100	19½	1.608	44	64	24	100	13
1.410	28	72	32	86	13	1.510	24	72	40	86	13	1.610	32	86	44	100	10½
1.412	24	64	28	72	14½	1.512	24	64	44	86	38	1.612	32	86	44	100	10
1.414	24	72	44	100	15½	1.514	24	72	48	86	35½	1.614	44	64	24	100	12
1.416	24	64	44	86	42½	1.516	24	72	40	86	12	1.616	40	56	24	100	19½
1.418	28	72	32	86	11½	1.518	32	86	44	100	22	1.618	24	64	32	72	14
1.420	28	72	32	86	11	1.520	28	86	48	100	13½	1.620	44	64	24	100	11
1.422	40	64	24	100	18½	1.522	24	72	40	86	11	1.622	44	64	24	100	10½
1.424	28	64	32	86	29	1.524	24	72	40	86	10½	1.624	24	64	32	72	13
1.426	24	64	28	72	12	1.526	24	72	40	86	10	1.626	24	72	44	86	17½
1.428	28	86	48	100	24	1.528	32	86	44	100	21	1.628	24	64	32	72	12½
1.430	32	86	40	100	16	1.530	28	72	40	100	10½	1.630	24	64	32	72	12
1.432	24	72	44	100	12½	1.532	28	72	40	100	10	1.632	28	72	44	100	11½
1.434	24	64	28	72	10½	1.534	28	86	48	100	11	1.634	24	64	32	72	17½
1.436	24	64	28	72	10	1.536	32	72	40	86	42	1.636	24	64	32	72	11
1.438	24	72	44	100	11½	1.538	24	72	48	100	16	1.638	32	86	48	100	23½
1.440	24	72	44	100	11	1.540	28	100	56	72	45	1.640	28	72	40	86	25
1.442	24	72	44	100	10½	1.542	24	72	48	100	15½	1.642	24	64	32	72	10
1.444	32	86	40	100	14	1.544	28	64	32	86	18½	1.644	24	64	40	86	19½
1.446	24	72	44	86	32	1.546	24	72	48	100	15	1.646	28	72	40	86	24½
1.448	28	72	40	100	21½	1.548	28	64	32	86	18	1.648	40	56	24	100	16

TABLE 9.—GEARS FOR MILLING CAMS.—*Continued*

Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle	Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle	Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle
1.650	28	64	40	100	19½	1.750	32	86	48	100	11½	1.850	28	64	44	100	16
1.652	40	56	24	100	15½	1.752	28	100	56	86	16	1.852	28	72	44	86	21½
1.654	24	72	44	86	14	1.754	28	72	48	100	20	1.854	44	56	24	100	10½
1.656	28	72	44	100	14½	1.756	32	86	48	100	10½	1.856	24	64	40	72	27
1.658	24	72	44	86	13½	1.758	32	72	44	100	26	1.858	24	64	44	86	14½
1.660	28	72	44	100	14	1.760	28	72	48	100	19½	1.860	32	72	44	100	18
1.662	32	86	48	100	21½	1.762	28	64	32	72	25	1.862	24	64	44	86	14
1.664	28	72	44	100	13½	1.764	24	72	48	86	18½	1.864	28	64	44	100	14½
1.666	28	64	32	72	31	1.766	28	72	40	86	12½	1.866	24	64	44	86	13½
1.668	24	72	44	86	12	1.768	32	72	48	100	34	1.868	28	64	44	100	14
1.670	28	72	44	100	12½	1.770	28	72	48	100	18½	1.870	24	64	44	86	13
1.672	24	64	40	86	16½	1.772	44	56	24	100	20	1.872	28	64	44	100	13½
1.674	24	72	44	86	11	1.774	24	72	48	86	17½	1.874	24	64	44	86	12½
1.676	24	72	44	86	10½	1.776	28	72	40	86	11	1.876	28	64	44	100	13
1.678	28	64	40	100	16½	1.778	44	56	24	100	19½	1.878	28	64	32	72	15
1.680	28	72	44	100	11	1.780	28	100	56	86	12½	1.880	24	64	44	86	11½
1.682	28	72	44	100	10½	1.782	32	64	40	100	27	1.882	28	64	32	72	14½
1.684	32	86	48	100	19½	1.784	24	56	40	86	26½	1.884	24	64	44	86	11
1.686	28	64	40	100	15½	1.786	28	100	56	86	11½	1.886	28	64	44	100	11½
1.688	40	56	24	100	10	1.788	24	72	48	86	16	1.888	28	72	44	86	18½
1.690	28	64	40	100	15	1.790	28	100	56	86	11	1.890	24	64	44	86	10
1.692	24	64	40	86	14	1.792	28	100	56	86	10½	1.892	32	72	48	100	27½
1.694	32	72	44	100	30	1.794	44	56	24	100	18	1.894	28	64	32	72	13
1.696	24	64	40	86	13½	1.796	28	64	32	72	22½	1.896	28	64	44	100	10
1.698	28	64	40	100	14	1.798	24	64	44	86	20½	1.898	28	64	32	72	12½
1.700	32	72	40	100	17	1.800	32	72	44	100	23	1.900	28	64	40	86	21
1.702	28	64	40	100	13½	1.802	28	64	32	72	22	1.902	28	64	32	72	12
1.704	28	64	40	72	45½	1.804	32	72	44	86	37½	1.904	24	64	48	86	24½
1.706	24	64	40	86	12	1.806	24	56	40	86	25	1.906	32	72	44	100	13
1.708	28	64	40	100	12½	1.808	28	72	48	100	14½	1.908	28	64	32	72	11
1.710	28	72	40	86	19	1.810	28	72	48	86	33½	1.910	32	72	44	100	12½
1.712	24	64	40	86	11	1.812	24	72	48	86	13	1.912	28	64	32	72	10½
1.714	32	64	40	100	31	1.814	24	64	44	86	19	1.914	28	64	32	72	10
1.716	28	72	40	86	18½	1.816	24	72	48	86	12½	1.916	24	56	40	86	16
1.718	24	64	40	86	10	1.818	28	72	44	86	24	1.918	28	72	44	86	15½
1.720	28	72	40	86	18	1.820	24	64	44	86	18½	1.920	32	72	44	100	11
1.722	24	44	32	86	32	1.822	44	56	24	100	15	1.922	28	72	44	86	15
1.724	28	100	56	86	19	1.824	40	86	44	100	27	1.924	28	64	40	86	19
1.726	24	56	40	86	30	1.826	24	72	48	86	11	1.926	32	72	44	100	10
1.728	32	72	40	100	13½	1.828	24	56	40	86	23½	1.928	28	64	44	86	30½
1.730	28	72	40	86	17	1.830	28	72	48	100	11½	1.930	24	56	40	86	14½
1.732	32	72	40	100	13	1.832	24	72	48	86	10	1.932	32	64	40	100	15
1.734	28	72	40	86	16½	1.834	44	56	24	100	13½	1.934	24	56	40	86	14
1.736	32	72	40	100	12½	1.836	28	72	48	100	10½	1.936	32	64	40	100	14½
1.738	32	56	40	100	40½	1.838	44	56	24	100	13	1.938	24	56	40	86	13½
1.740	32	86	48	100	13	1.840	24	64	44	86	16½	1.940	28	64	48	100	22½
1.742	32	72	40	100	11½	1.842	32	72	40	86	27	1.942	24	56	40	86	13
1.744	32	86	48	100	12½	1.844	28	64	32	72	18½	1.944	32	56	40	86	43
1.746	24	64	44	86	24½	1.846	28	64	44	100	16½	1.946	28	72	44	86	12
1.748	32	72	40	100	10½	1.848	44	56	24	100	11½	1.948	32	72	40	86	19½

TABLE 9.—GEARS FOR MILLING CAMS.—*Continued*

Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle	Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle	Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle
1.950	28	72	44	86	11½	2.050	28	64	48	100	12½	2.150	32	72	44	86	19
1.952	40	86	44	100	17½	2.052	28	64	44	86	23½	2.152	32	64	44	100	12
1.954	24	64	48	86	21	2.054	28	64	48	100	12	2.154	24	64	44	72	20
1.956	32	72	48	100	23½	2.056	40	86	48	100	23	2.156	32	64	44	100	11½
1.958	40	86	44	100	17	2.058	24	64	48	86	10½	2.158	24	56	40	72	25
1.960	28	72	44	86	10	2.060	32	72	48	100	15	2.160	32	64	44	100	11
1.962	48	56	24	100	17½	2.062	24	56	40	72	30	2.162	40	86	48	100	14½
1.964	24	64	40	72	19½	2.064	44	48	28	100	36½	2.164	32	64	40	86	21½
1.966	28	64	40	86	15	2.066	32	56	40	86	39	2.166	32	64	48	100	25½
1.968	40	86	44	100	16	2.068	28	64	48	100	10	2.168	32	56	40	100	18½
1.970	32	64	40	100	10	2.070	32	72	48	100	14	2.170	32	72	48	86	29
1.972	48	56	24	100	16½	2.072	32	56	40	100	25	2.172	28	64	44	86	14
1.974	24	44	32	86	13½	2.074	32	72	48	100	13½	2.174	32	56	40	100	18
1.976	28	64	44	86	28	2.076	28	72	48	86	17	2.176	56	64	32	100	39
1.978	24	44	32	86	13	2.078	32	72	48	100	13	2.178	40	72	44	100	27
1.980	28	64	48	100	19½	2.080	32	64	44	100	19	2.180	40	86	48	100	12½
1.982	24	44	32	86	12½	2.082	32	72	48	100	12½	2.182	28	72	56	86	30½
1.984	28	48	40	86	43	2.084	28	64	40	72	31	2.184	24	56	44	72	33½
1.986	24	44	32	86	12	2.086	32	72	48	100	12	2.186	32	72	44	86	16
1.988	28	56	32	72	26½	2.088	28	100	56	72	16½	2.188	28	56	32	72	10
1.990	28	64	40	86	12	2.090	32	72	48	100	11½	2.190	32	56	40	86	34½
1.992	48	56	24	100	14½	2.092	28	72	48	86	15½	2.192	40	86	48	100	11
1.994	28	64	40	86	11½	2.094	32	72	48	100	11	2.194	28	64	40	72	25½
1.996	24	44	32	86	10½	2.096	28	64	44	86	20½	2.196	40	86	48	100	10½
1.998	28	64	40	86	11	2.098	32	64	44	100	17½	2.198	44	86	48	100	20½
2.000	48	56	24	100	13½	2.100	28	44	32	86	27½	2.200	24	56	40	72	22½
2.002	40	86	44	100	12	2.102	28	72	48	86	14½	2.202	32	72	44	86	14½
2.004	28	64	40	86	10	2.104	28	100	56	72	15	2.204	28	64	44	86	10
2.006	40	86	44	100	11½	2.106	28	72	48	86	14	2.206	32	72	44	86	14
2.008	48	56	24	100	12½	2.108	40	44	24	100	15	2.208	32	56	40	100	15
2.010	32	72	40	86	13½	2.110	28	64	44	86	19½	2.210	48	100	56	86	45
2.012	48	56	24	100	12	2.112	40	44	24	100	14½	2.212	32	64	40	86	18
2.014	32	72	40	86	13	2.114	28	56	32	72	18	2.214	24	64	44	72	15
2.016	40	86	44	100	10	2.116	28	64	44	86	19	2.216	32	72	44	86	13
2.018	32	72	40	86	12½	2.118	28	100	56	72	13½	2.218	32	56	40	100	14
2.020	28	72	48	86	21½	2.120	28	72	48	86	12½	2.220	32	72	44	86	12½
2.022	32	72	40	86	12	2.122	28	100	56	72	13	2.222	28	64	48	86	24½
2.024	28	64	48	100	15½	2.124	28	72	48	86	12	2.224	32	72	44	86	12
2.026	48	56	24	100	10	2.126	28	100	56	72	12½	2.226	44	86	48	100	25
2.028	28	64	48	100	15	2.128	28	64	44	86	18	2.228	32	72	44	86	11½
2.030	24	64	40	72	13	2.130	28	100	56	72	12	2.230	32	64	40	86	16½
2.032	32	72	40	86	10½	2.132	24	64	44	72	21½	2.232	32	72	44	86	11
2.034	24	64	40	72	12½	2.134	28	100	56	72	11½	2.234	44	48	28	100	29½
2.036	32	72	40	86	10	2.136	28	56	32	72	16	2.236	32	72	44	86	10½
2.038	28	64	48	100	14	2.138	28	72	48	86	10	2.238	24	64	44	72	12½
2.040	32	72	48	100	17	2.140	24	56	40	72	26	2.240	32	56	40	100	11½
2.042	28	64	48	100	13½	2.142	28	100	56	72	10½	2.242	24	64	44	72	12
2.044	40	44	24	100	20½	2.144	40	72	48	100	36½	2.244	32	56	40	100	11
2.046	28	64	48	100	13	2.146	28	56	32	72	15	2.246	24	64	44	72	11½
2.048	24	64	40	72	10½	2.148	44	86	48	100	29	2.248	32	56	40	100	10½

TABLE 9.—GEARS FOR MILLING CAMS.—*Continued*

Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle	Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle	Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle
2.250	24	64	44	72	11	2.500	28	64	48	72	31	2.750	28	64	48	72	19½
2.255	32	64	48	100	20	2.505	24	56	44	72	17	2.755	44	40	32	100	38½
2.260	44	56	32	100	26	2.510	28	40	44	86	45½	2.760	28	44	48	86	39
2.265	28	44	32	86	17	2.515	32	64	44	86	10½	2.765	48	64	28	56	42½
2.270	28	44	32	86	16½	2.520	44	48	28	100	11	2.770	28	48	44	72	39
2.275	32	64	40	86	12	2.525	48	56	32	100	23	2.775	40	72	44	86	12½
2.280	28	64	44	72	31½	2.530	24	56	44	72	15	2.780	40	72	44	86	12
2.285	44	86	48	100	21½	2.535	32	56	40	86	17½	2.785	24	44	48	72	40
2.290	24	44	40	86	25½	2.540	32	64	48	86	24½	2.790	28	48	44	72	38½
2.295	32	64	48	100	17	2.545	32	56	44	86	29½	2.795	32	48	40	72	41
2.300	24	56	40	72	15	2.550	28	64	44	72	17½	2.800	24	56	48	72	11½
2.305	24	56	40	72	14½	2.555	32	56	40	86	16	2.805	24	56	48	72	11
2.310	24	56	40	72	14	2.560	32	64	48	86	23½	2.810	44	56	24	64	17½
2.315	24	56	40	72	13½	2.565	28	40	32	86	10	2.815	28	44	40	86	18
2.320	28	44	32	86	11½	2.570	44	48	40	100	45½	2.820	40	56	44	86	39½
2.325	28	44	32	86	11	2.575	24	56	44	72	10½	2.825	32	56	44	72	36
2.330	40	100	56	72	41½	2.580	40	72	56	86	44½	2.830	48	64	28	56	41
2.335	28	64	48	86	17	2.585	32	56	40	86	13½	2.835	28	48	40	72	29
2.340	24	56	48	72	35	2.590	32	56	40	86	13	2.840	40	56	44	86	39
2.345	24	56	40	72	10	2.595	44	40	32	100	42½	2.845	28	44	40	86	16
2.350	28	64	44	72	28½	2.600	32	56	40	86	12	2.850	28	56	64	86	40
2.355	44	86	48	100	16½	2.605	32	56	40	86	11½	2.855	28	44	48	86	36½
2.360	32	64	48	100	10½	2.610	32	64	40	72	20	2.860	40	56	44	86	38½
2.365	24	56	48	86	8½	2.615	44	48	40	100	44½	2.865	24	44	48	72	38
2.370	44	56	32	100	19½	2.620	28	64	44	72	11½	2.870	44	48	40	100	38½
2.375	28	64	48	86	13½	2.625	44	56	24	64	27	2.875	40	64	48	86	34½
2.380	32	100	56	72	17	2.630	48	56	32	100	16½	2.880	48	100	56	72	39½
2.385	32	72	56	86	34½	2.635	40	72	44	86	22	2.885	24	44	48	72	37½
2.390	28	64	40	72	10½	2.640	48	100	56	72	45	2.890	44	48	40	100	38
2.395	40	72	44	100	11½	2.645	24	40	44	86	30½	2.895	32	56	44	72	34
2.400	56	64	32	100	31	2.650	40	56	44	86	43½	2.900	28	44	40	86	11½
2.405	28	64	48	86	10	2.655	56	64	32	100	18½	2.905	40	72	48	86	20½
2.410	32	100	56	72	14½	2.660	44	48	40	100	43½	2.910	28	44	40	86	10½
2.415	44	86	48	100	10½	2.665	28	64	48	72	24	2.915	28	40	44	86	35½
2.420	32	100	56	72	13½	2.670	28	48	44	72	41½	2.920	28	48	44	72	35
2.425	32	100	56	72	13	2.675	48	64	28	56	44½	2.925	40	64	48	86	33
2.430	32	100	56	72	12½	2.680	28	44	48	86	41	2.930	32	64	44	72	16½
2.435	32	72	48	86	11	2.685	48	100	56	72	44	2.935	48	64	28	56	38½
2.440	32	72	48	86	10½	2.690	40	64	44	100	12	2.940	40	64	48	100	11½
2.445	44	56	32	100	13½	2.695	40	64	44	100	11½	2.945	40	72	56	86	35½
2.450	24	64	48	72	11½	2.700	28	44	48	86	40½	2.950	40	64	48	100	10½
2.455	40	72	48	100	23	2.705	56	64	32	100	15	2.955	48	64	28	56	38
2.460	28	64	48	72	32½	2.710	40	72	56	86	41½	2.960	24	44	48	72	35½
2.465	32	64	44	86	15½	2.715	40	56	44	86	42	2.965	32	64	44	72	14
2.470	28	40	32	86	18½	2.720	48	64	28	56	43½	2.970	32	64	48	72	27
2.475	32	64	40	72	27	2.725	44	48	40	100	42	2.975	40	56	44	86	35½
2.480	44	48	28	100	15	2.730	48	100	56	72	43	2.980	48	40	28	100	27½
2.485	28	72	56	86	11	2.735	44	40	32	100	39	2.985	44	48	40	100	35½
2.490	28	72	56	86	10½	2.740	28	44	48	86	39½	2.990	28	48	44	72	33
2.495	24	44	40	86	10½	2.745	40	72	44	86	15	2.995	48	64	28	56	37

TABLE 9.—GEARS FOR MILLING CAMS.—*Continued*

Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle	Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle	Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle
3.000	40	100	56	64	31	3.250	44	64	48	100	10	3.500	28	48	44	72	11
3.005	40	64	48	86	30½	3.255	32	48	40	72	28½	3.505	28	48	44	72	10½
3.010	28	56	64	86	36	3.260	32	56	44	72	21	3.510	40	72	56	86	14
3.015	48	64	28	56	36½	3.265	48	100	56	72	29	3.515	28	40	44	86	11
3.020	48	100	56	72	36	3.270	40	56	44	86	26½	3.520	24	44	48	72	14½
3.025	40	100	56	72	13½	3.275	44	40	32	100	21½	3.525	44	48	40	100	16
3.030	40	64	44	72	37½	3.280	48	64	28	56	29	3.530	40	56	44	86	15
3.035	24	40	48	86	25	3.285	32	48	40	72	27½	3.535	24	44	48	72	13½
3.040	44	48	40	100	34	3.290	32	44	40	86	13½	3.540	48	100	56	72	18½
3.045	32	64	48	72	24	3.295	24	44	48	72	25	3.545	40	56	44	86	14
3.050	40	56	44	100	14	3.300	32	48	40	72	27	3.550	24	44	48	72	12½
3.055	56	44	28	86	42½	3.305	40	72	56	86	24	3.555	40	56	48	100	19½
3.060	28	44	48	86	30½	3.310	44	48	40	100	25½	3.560	40	56	44	86	13
3.065	40	56	44	86	33	3.315	32	48	40	72	26½	3.565	40	64	44	72	21
3.070	28	40	44	86	31	3.320	28	40	44	86	22	3.570	48	100	56	72	17
3.075	44	48	40	100	33	3.325	40	56	44	86	24½	3.575	24	44	48	72	10½
3.080	40	64	48	86	28	3.330	28	56	64	86	26½	3.580	44	48	40	100	12½
3.085	28	56	64	86	34	3.335	28	64	56	72	11½	3.585	48	40	32	100	21
3.090	48	64	28	56	34½	3.340	40	64	44	72	29	3.590	40	64	48	72	30½
3.095	48	100	56	72	34	3.345	32	44	48	86	34½	3.595	56	40	28	100	23½
3.100	24	44	48	72	31½	3.350	44	48	40	100	24	3.600	44	48	40	100	11
3.105	40	100	56	64	27½	3.355	48	100	56	72	26	3.605	48	64	28	56	16
3.110	44	48	40	100	32	3.360	40	56	48	100	11½	3.610	28	56	64	86	14
3.115	28	48	40	72	16	3.365	28	40	44	86	20	3.615	32	44	40	72	26½
3.120	44	64	48	100	19	3.370	48	64	28	56	26	3.620	48	40	32	100	19½
3.125	32	56	44	72	26½	3.375	44	48	40	100	23	3.625	44	56	48	100	16
3.130	32	56	48	86	11	3.380	32	56	48	72	27½	3.630	32	48	40	72	11½
3.135	28	44	48	86	28	3.385	48	64	28	56	25½	3.635	28	40	48	86	21½
3.140	32	56	48	86	10	3.390	48	40	32	100	28	3.640	28	56	64	86	12
3.145	48	64	28	56	33	3.395	32	56	44	72	13½	3.645	48	100	56	72	12½
3.150	28	44	48	86	27½	3.400	40	56	44	86	21½	3.650	40	72	64	86	28
3.155	28	64	56	72	22	3.405	28	44	48	86	16½	3.655	32	64	56	72	20
3.160	44	48	40	100	30½	3.410	32	48	40	72	23	3.660	28	48	56	86	15½
3.165	24	44	48	72	29½	3.415	28	40	44	86	17½	3.665	48	100	56	72	11
3.170	28	48	40	72	12	3.420	32	40	48	86	40	3.670	48	100	56	72	10½
3.175	32	48	40	72	31	3.425	28	56	64	86	23	3.675	48	64	28	56	11½
3.180	40	56	44	86	29½	3.430	28	44	48	86	15	3.680	32	56	48	72	15
3.185	40	100	56	64	24½	3.435	44	48	40	100	20½	3.685	28	48	56	86	14
3.190	28	56	64	86	31	3.440	48	100	56	64	35	3.690	56	48	24	64	32½
3.195	44	72	48	86	20½	3.445	28	44	48	86	14	3.695	44	56	48	100	11½
3.200	48	100	56	72	31	3.450	28	56	64	86	22	3.700	48	40	32	100	15½
3.205	28	40	44	86	26½	3.455	40	56	44	86	19	3.705	32	56	48	72	13½
3.210	24	44	48	72	28	3.460	40	72	56	86	17	3.710	44	100	56	64	15½
3.215	40	64	48	72	39½	3.465	32	64	56	72	27	3.715	28	48	56	86	12
3.220	56	44	28	86	39	3.470	28	48	56	86	24	3.720	32	56	48	72	12½
3.225	24	44	48	72	27½	3.475	40	56	44	86	18	3.725	56	44	28	86	26
3.230	48	40	28	100	16	3.480	28	48	44	72	12½	3.730	48	64	32	56	29½
3.235	32	72	64	86	12	3.485	40	56	44	86	17½	3.735	40	64	44	72	12
3.240	24	44	48	72	27	3.490	32	40	44	86	31½	3.740	56	44	28	86	25½
3.245	28	40	44	86	25	3.495	24	44	48	72	16	3.745	40	64	48	72	26

TABLE 9.—GEARS FOR MILLING CAMS.—*Continued*

Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle	Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle	Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle
3·750	32	44	48	86	22½	4·000	28	40	48	72	31	4·250	28	48	56	72	20½
3·755	40	64	44	72	10½	4·005	40	64	48	72	16	4·255	56	40	28	86	21
3·760	44	64	48	86	11½	4·010	56	40	32	100	26½	4·260	44	72	64	86	20½
3·765	32	64	56	72	14½	4·015	40	64	48	72	15½	4·265	56	44	28	64	40
3·770	48	40	32	100	11	4·020	40	72	64	86	13½	4·270	44	64	56	86	17½
3·775	48	100	56	64	26	4·025	40	64	48	72	15	4·275	32	44	56	86	25½
3·780	40	56	48	86	18½	4·030	32	40	48	86	25½	4·280	28	40	48	72	23½
3·785	40	48	44	72	42	4·035	44	64	56	72	41	4·285	40	56	44	72	11
3·790	32	48	44	72	21½	4·040	48	64	32	56	19½	4·290	28	48	56	72	19
3·795	56	40	28	100	14½	4·045	56	48	44	100	38	4·295	56	48	24	64	11
3·800	56	44	28	86	23½	4·050	40	72	64	86	11½	4·300	44	72	64	86	19
3·805	44	72	56	86	17	4·055	40	48	44	86	18	4·305	44	56	48	86	11
3·810	56	40	32	86	43	4·060	40	64	48	72	13	4·310	32	44	56	86	24½
3·815	56	44	28	86	23	4·065	44	64	48	72	27½	4·315	28	48	56	72	18
3·820	56	40	28	100	13	4·070	44	72	64	86	26½	4·320	44	64	48	72	19½
3·825	44	72	56	86	16	4·075	56	44	28	86	10½	4·325	44	72	64	86	18
3·830	40	64	56	72	38	4·080	44	56	48	86	21½	4·330	28	56	64	72	13
3·835	28	40	48	86	11	4·085	56	48	24	64	21	4·335	56	40	28	86	18
3·840	32	48	44	72	19½	4·090	40	64	48	72	11	4·340	72	48	24	64	39½
3·845	28	44	48	72	25	4·095	28	48	56	72	25½	4·345	64	48	24	56	40½
3·850	40	64	48	72	22½	4·100	48	100	56	64	12½	4·350	28	48	56	72	16½
3·855	56	40	28	100	10½	4·105	44	72	64	86	25½	4·355	28	56	64	72	11½
3·860	56	40	28	100	10	4·110	48	64	32	56	16½	4·360	32	44	56	86	23
3·865	56	40	28	86	32	4·115	40	56	44	72	19½	4·365	56	40	32	100	13
3·870	32	40	44	86	19	4·120	48	64	32	56	16	4·370	56	40	28	86	16½
3·875	32	48	44	72	18	4·125	28	44	48	72	13½	4·375	32	44	56	86	22½
3·880	32	44	56	86	35	4·130	48	100	56	64	10½	4·380	48	72	64	86	28
3·885	44	72	56	86	12½	4·135	32	56	64	86	13½	4·385	40	48	64	86	45
3·890	40	64	48	72	21	4·140	28	40	48	72	27½	4·390	56	40	32	100	11½
3·895	40	48	44	86	24	4·145	28	48	56	72	24	4·395	44	64	56	86	11
3·900	56	44	28	72	38	4·150	48	64	32	56	14½	4·400	40	56	48	72	22½
3·905	28	44	48	72	23	4·155	44	72	64	86	24	4·405	44	64	48	72	16
3·910	56	48	28	64	40	4·160	56	40	32	86	37	4·410	56	44	24	64	22½
3·915	48	64	32	56	24	4·165	44	64	56	86	21½	4·415	40	56	48	72	22
3·920	32	44	40	72	14	4·170	44	64	48	72	24½	4·420	48	72	64	86	27
3·925	40	56	48	86	10	4·175	56	44	24	64	29	4·425	64	40	32	86	42
3·930	56	44	28	86	18½	4·180	56	40	28	86	23½	4·430	28	48	56	72	12½
3·935	32	48	44	72	15	4·185	40	56	44	72	16½	4·435	48	64	56	72	40½
3·940	40	64	48	72	19	4·190	64	48	32	72	45	4·440	44	72	64	86	12½
3·945	48	64	32	56	23	4·195	28	40	48	72	26	4·445	56	48	44	100	30
3·950	48	72	56	86	24½	4·200	48	64	32	56	11½	4·450	32	44	56	86	20
3·955	32	44	48	86	13	4·205	48	44	40	100	15½	4·455	86	56	24	72	29½
3·960	28	44	48	72	21	4·210	56	40	32	100	20	4·460	40	56	48	72	20½
3·965	56	48	24	64	25	4·215	48	44	40	100	15	4·465	44	64	48	72	13
3·970	32	44	48	86	12	4·220	32	44	56	86	27	4·470	44	48	56	86	41½
3·975	32	56	64	72	38½	4·225	48	44	40	100	14½	4·475	28	40	48	72	16½
3·980	32	40	44	86	13½	4·230	28	40	48	72	25	4·480	40	44	48	86	28
3·985	40	64	48	72	17	4·235	40	56	44	72	14	4·485	56	44	28	72	25
3·990	44	56	48	86	24½	4·240	32	44	48	72	29	4·490	32	48	56	72	30
3·995	40	64	48	72	16½	4·245	56	48	24	64	14	4·495	32	44	48	72	22

TABLE 9.—GEARS FOR MILLING CAMS.—*Continued*

Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle	Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle	Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle
4.500	56	44	32	64	45	4.750	32	44	48	72	11½	5.000	48	64	56	72	31
4.505	56	44	28	64	36	4.755	64	40	32	86	37	5.005	56	44	28	64	26
4.510	44	64	56	72	32½	4.760	44	56	64	86	35½	5.010	56	48	28	64	11
4.515	48	64	44	56	40	4.765	64	48	24	56	33½	5.015	40	48	44	72	10
4.520	86	56	24	72	28	4.770	86	48	24	72	37	5.020	40	44	56	86	32
4.525	40	48	56	86	33½	4.775	86	56	24	64	34	5.025	64	48	32	72	32
4.530	56	72	64	86	38½	4.780	40	64	56	72	10½	5.030	56	48	44	100	11½
4.535	40	44	56	86	40	4.785	44	56	48	72	24	5.035	44	56	48	72	16
4.540	64	48	32	72	40	4.790	44	56	64	86	35	5.040	32	44	56	72	27
4.545	72	56	24	64	19½	4.795	86	56	24	72	20½	5.045	64	48	24	56	28
4.550	48	72	64	86	23½	4.800	64	44	32	86	27½	5.050	48	64	40	56	19½
4 555	56	44	28	72	23	4.805	44	40	48	86	38½	5.055	56	48	44	100	10
4.560	48	64	56	86	21	4.810	48	64	56	86	10	5.060	86	64	28	72	14½
4.565	28	40	48	72	12	4.815	32	40	44	72	10	5.065	86	48	24	72	32
4.570	32	44	48	72	19½	4.820	40	44	56	86	35½	5.070	40	56	64	86	17½
4.575	32	44	56	86	15	4.825	64	48	32	72	35½	5.075	40	44	56	86	31
4.580	48	64	44	56	39	4.830	86	56	24	64	33	5.080	64	48	32	72	31
4.585	32	44	56	86	14½	4.835	48	64	40	56	25½	5.085	86	56	24	64	28
4.590	48	64	56	86	20	4.840	56	48	28	64	18½	5.090	32	48	56	72	11
4.595	32	44	56	86	14	4,845	32	56	64	72	17½	5.095	56	40	32	86	12
4.600	40	56	48	72	15	4.850	56	44	28	72	11½	5.100	32	40	48	72	17
4.605	32	44	56	86	13½	4.855	86	56	24	72	18½	5.105	40	44	64	86	41
4.610	40	56	48	72	14½	4.860	44	48	56	86	35½	5.110	56	72	64	86	28
4.615	32	44	56	86	13	4.865	40	44	48	86	16½	5.115	40	48	56	86	19½
4.620	40	56	48	72	14	4.870	48	72	64	86	11	5.120	44	40	48	86	33½
4.625	44	56	48	72	28	4.875	40	56	64	86	23½	5.125	56	44	28	64	23
4.630	86	56	24	64	36½	4.880	86	44	24	72	41½	5.130	64	40	32	86	30½
4.635	40	44	48	86	24	4.885	48	64	44	56	34	5.135	40	56	64	86	15
4.640	40	56	48	72	13	4.890	44	48	56	86	35	5.140	40	44	48	72	32
4.645	48	64	56	86	18	4.895	32	56	64	72	15½	5.145	40	48	56	86	18½
4.650	32	40	44	72	18	4.900	72	44	24	64	37	5.150	48	64	56	72	28
4.655	56	44	32	64	43	4.905	64	44	32	86	25	5.155	86	40	24	72	44
4.660	64	40	32	86	38½	4.910	86	56	24	64	31½	5.160	40	48	56	86	18
4.665	40	44	56	86	38	4.915	72	48	28	64	41½	5.165	44	64	56	72	15
4.670	64	48	32	72	38	4.920	48	64	56	72	32½	5.170	72	44	24	56	42½
4.675	48	64	44	56	37½	4.925	56	40	32	86	19	5.175	32	40	48	72	14
4.680	64	48	24	56	35	4.930	56	48	28	64	15	5.180	56	72	64	86	26½
4.685	56	44	24	64	11	4.935	56	72	64	86	31½	5.185	56	40	48	100	39½
4.690	32	44	56	72	34	4.940	32	56	64	72	13½	5.190	40	56	64	86	12½
4.695	40	64	56	72	15	4.945	86	56	24	72	15	5.195	44	48	56	86	29½
4.700	44	56	64	86	36½	4.950	32	56	64	72	13	5.200	64	48	24	56	24½
4.705	48	72	64	86	18½	4.955	56	40	28	64	36	5.205	64	32	28	72	48
4.710	32	56	64	72	22	4.960	32	56	64	72	12½	5.210	44	56	64	86	27
4.715	56	48	28	64	22½	4.965	64	40	32	86	33½	5.215	72	48	24	64	22
4.720	56	44	28	72	17½	4.970	64	48	32	72	33	5.220	48	64	56	72	26½
4.725	56	48	44	100	23	4.975	44	64	56	72	21½	5.225	48	56	64	86	35
4.730	44	56	64	86	36	4.980	86	48	24	72	33½	5.230	44	64	56	72	12
4.735	44	48	56	86	37½	4.985	44	56	64	86	31½	5.235	40	56	64	86	10
4.740	72	56	24	64	10½	4.990	72	48	24	64	27½	5.240	86	56	24	64	24½
4.745	56	44	28	72	16½	4.995	32	44	56	72	28	5.245	32	44	56	72	22

TABLE 9.—GEARS FOR MILLING CAMS.—*Continued*

Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle	Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle	Lead	Gear on Worm	1st Intermediate	2nd Intermediate	Gear on Screw	Angle
5.250	56	40	28	64	31	5.500	64	32	28	72	45	5.750	64	48	32	72	14
5.255	44	56	64	86	26	5.505	56	72	64	86	18	5.755	86	48	24	72	15
5.260	64	48	24	56	23	5.510	72	56	32	64	31	5.760	86	64	40	72	39½
5.265	48	64	56	72	25½	5.515	44	48	56	86	22½	5.765	44	48	56	86	15
5.270	44	48	56	86	28	5.520	64	40	32	86	22	5.770	64	44	28	56	37½
5.275	40	44	56	86	27	5.525	86	44	24	72	32	5.775	48	64	44	56	11
5.280	64	48	32	72	27	5.530	72	48	32	64	42½	5.780	40	44	56	86	12
5.285	64	40	32	72	42	5.535	56	72	64	86	17	5.785	64	48	32	72	12
5.290	56	44	48	100	30	5.540	64	40	32	86	21½	5.790	64	40	32	86	13
5.295	44	48	56	86	27½	5.545	40	44	56	86	20½	5.795	86	48	24	72	14
5.300	40	44	48	72	29	5.550	56	72	64	86	16½	5.800	64	44	24	56	21½
5.305	64	40	32	86	27	5.555	48	64	44	56	19½	5.805	44	48	56	72	35½
5.310	56	44	28	64	17½	5.560	48	44	56	86	38½	5.810	86	48	28	72	33½
5.315	56	40	28	72	12½	5.565	64	40	32	72	38½	5.815	86	44	24	64	37
5.320	44	56	64	86	24½	5.570	86	40	24	72	39	5.820	64	44	24	56	21
5.325	56	40	28	72	12	5.575	86	48	24	72	21	5.825	64	40	32	72	35
5.330	64	44	32	86	10	5.580	40	44	56	86	19½	5.830	86	48	24	72	12½
5.335	64	48	24	56	21	5.585	86	44	24	72	31	5.835	64	40	32	86	11½
5.340	86	56	24	64	22	5.590	40	48	64	72	41	5.840	44	48	56	72	35
5.345	86	48	24	72	26½	5.595	56	40	28	64	24	5.845	64	40	32	86	11
5.350	72	48	24	64	18	5.600	86	56	24	64	13½	5.850	86	56	32	72	31
5.355	40	56	64	72	32½	5.605	48	64	44	56	18	5.855	48	44	56	86	34½
5.360	64	44	32	72	34	5.610	40	44	56	72	37½	5.860	64	40	32	72	34½
5.365	44	48	56	86	26	5.615	86	44	24	64	40	5.865	64	40	28	72	19½
5.370	64	48	24	56	20	5.620	64	48	32	72	18½	5.870	72	48	32	64	38½
5.375	86	44	28	72	45	5.625	86	56	32	72	34½	5.875	56	40	44	100	17½
5.380	32	44	56	72	18	5.630	86	48	24	72	19½	5.880	86	56	32	72	30½
5.385	56	72	64	86	21½	5.635	48	64	44	56	17	5.885	72	44	28	56	44
5.390	86	48	24	72	25½	5.640	56	72	64	86	13	5.890	44	56	64	72	32½
5.395	32	44	56	72	17½	5.645	44	40	56	86	38	5.895	44	40	48	72	36½
5.400	56	32	28	72	37½	5.650	48	64	44	56	16½	5.900	56	64	40	48	36
5.405	64	44	28	56	42	5.655	64	44	32	72	29	5.905	40	44	48	72	13
5.410	44	48	56	86	25	5.660	48	64	56	72	14	5.910	72	48	32	64	38
5.415	86	64	40	72	43½	5.665	48	64	44	56	16	5.915	40	48	64	72	37
5.420	72	48	24	64	15½	5.670	56	40	44	100	23	5.920	40	48	56	72	24
5.425	48	64	44	56	23	5.675	56	32	28	72	33½	5.925	86	64	32	56	39½
5.430	86	64	32	56	45	5.680	86	48	24	72	18	5.930	86	44	24	64	36
5.435	64	48	32	72	23½	5.685	44	56	64	86	13½	5.935	72	44	28	64	34
5.440	44	56	64	86	21½	5.690	48	44	64	86	45½	5.940	86	56	32	72	29½
5.445	48	64	44	56	22½	5.695	48	64	56	72	12½	5.945	44	40	48	86	14½
5.450	64	48	24	56	17½	5.700	56	72	64	86	10	5.950	72	48	32	64	37½
5.455	64	48	32	72	23	5.705	40	44	56	86	15½	5.955	44	56	64	72	31½
5.460	64	40	32	86	23½	5.710	64	48	32	72	15½	5.960	40	44	48	72	10½
5.465	44	56	64	72	38½	5.715	40	48	64	72	39½	5.965	40	48	56	72	23
5.470	72	48	24	64	13½	5.720	40	44	56	72	36	5.970	44	40	48	72	35½
5.475	64	48	32	72	22½	5.725	86	44	24	72	28½	5.975	56	44	48	100	12
5.480	48	56	64	72	44	5.730	48	64	44	56	13½	5.980	44	48	56	72	33
5.485	72	48	32	64	43	5.735	48	64	56	72	10½	5.985	40	56	64	72	19½
5.490	86	44	24	64	41½	5.740	44	56	64	86	11	5.990	72	48	32	64	37
5.495	44	48	56	86	23	5.745	72	48	32	64	40	5.995	44	48	64	86	28½

TABLE 10.—GEARING FOR CUTTING WORM AND HELICAL GEARS

Leads from 0.670 to 3.143 Inches

$$\frac{\text{Lead}}{10} = \frac{\text{Driven}}{\text{Drivers}} = \frac{\text{Second} \times \text{Worm}}{\text{First} \times \text{Screw}}$$

Lead of Spiral in Inches	Gear on Worm (Driven)	First Intermediate Gear (Driver)	Second Intermediate Gear (Driven)	Gear for Screw (Driver)	Lead of Spiral in Inches	Gear on Worm (Driven)	First Intermediate Gear (Driver)	Second Intermediate Gear (Driven)	Gear for Screw (Driver)	Lead of Spiral in Inches	Gear on Worm (Driven)	First Intermediate Gear (Driver)	Second Intermediate Gear (Driven)	Gear for Screw (Driver)
0.670	24	86	24	100	1.714	40	56	24	100	2.442	28	64	48	86
0.781	24	86	28	100	1.744	24	64	40	86	2.444	40	72	44	100
0.800	24	72	24	100	1.750	28	64	40	100	2.450	56	64	28	100
0.893	24	86	32	100	1.778	32	72	40	100	2.456	44	86	48	100
0.900	24	64	24	100	1.786	32	86	48	100	2.481	32	72	48	86
0.930	24	72	24	86	1.809	28	72	40	86	2 489	32	100	56	72
0.933	24	72	28	100	1.823	28	100	56	86	2.500	24	64	48	72
1.029	24	56	24	100	1.860	24	72	48	86	2.514	44	56	32	100
1.042	28	86	32	100	1.867	28	72	48	100	2.532	28	72	56	86
1.047	24	64	24	86	1.886	44	56	24	100	2.537	24	44	40	86
1.050	24	64	28	100	1.919	24	64	44	86	2.558	32	64	44	86
1.067	24	72	32	100	1.925	28	64	44	100	2.567	44	48	28	100
1.085	24	72	28	86	1.944	28	64	32	72	2.605	28	40	32	86
1.116	24	86	40	100	1.956	32	72	44	100	2.619	24	56	44	72
1.196	24	56	24	86	1.990	28	72	44	86	2.658	32	56	40	86
1.200	24	64	32	100	1.993	24	56	40	86	2.667	40	72	48	100
1.221	24	64	28	86	2.000	32	64	40	100	2.674	28	64	44	72
1.228	24	86	44	100	2.030	24	44	32	86	2.713	28	48	40	86
1.240	24	72	32	86	2.035	28	64	40	86	2.743	48	56	32	100
1.244	28	72	32	100	2.047	40	86	44	100	2.750	40	64	44	100
1.302	28	86	40	100	2.057	48	56	24	100	2.778	32	64	40	72
1.333	24	72	40	100	2.067	32	72	40	86	2.791	32	64	48	86
1.340	24	86	48	100	2.083	24	64	40	72	2.800	56	64	32	100
1.371	32	56	24	100	2.093	24	64	48	86	2.842	40	72	44	86
1.395	24	64	32	86	2.100	28	64	48	100	2.849	28	64	56	86
1.400	28	64	32	100	2.133	32	72	48	100	2.857	24	56	48	72
1.433	28	86	44	100	2.171	28	72	48	86	2.865	44	100	56	86
1.447	28	72	32	86	2.178	28	100	56	72	2.880	48	40	24	100
1.458	24	64	28	72	2.182	40	44	24	100	2.894	32	72	56	86
1.467	24	72	44	100	2.193	24	56	44	86	2.917	28	64	48	72
1.488	32	86	40	100	2.200	32	64	44	100	2.924	32	56	44	86
1.500	40	64	24	100	2.222	28	56	32	72	2.933	44	72	48	100
1.550	24	72	40	86	2.233	40	86	48	100	2.946	44	56	24	64
1.556	28	72	40	100	2.238	28	64	44	86	2.960	28	44	40	86
1.563	28	86	48	100	2.274	32	72	44	86	2.984	28	48	44	86
1.595	24	56	32	86	2.286	32	56	40	100	3.000	40	64	48	100
1.600	24	72	48	100	2.292	24	64	44	72	3.044	24	44	48	86
1.628	28	64	32	86	2.326	32	64	40	86	3.056	32	64	44	72
1.637	32	86	44	100	2.368	28	44	32	86	3.070	24	40	44	86
1.650	44	64	24	100	2.381	24	56	40	72	3.101	40	72	48	86
1.667	24	64	32	72	2.392	24	56	48	86	3.111	40	100	56	72
1.705	24	72	44	86	2.400	32	64	48	100	3.126	48	100	56	86
1.711	28	72	44	100	2.431	28	64	40	72	3.143	40	56	44	100

For leads up to 3.143 inches.

GEARING FOR CUTTING WORM AND HELICAL GEARS—*Continued*

Leads from 3.175 to 6.667 Inches

$$\frac{\text{Lead}}{10} = \frac{\text{Driven}}{\text{Drivers}} = \frac{\text{Second} \times \text{Worm}}{\text{First} \times \text{Screw}}$$

Lead of Spiral in Inches	Gear on Worm (Driven)	First Intermediate Gear (Driver)	Second Intermediate Gear (Driven)	Gear for Screw (Driver)	Lead of Spiral in Inches	Gear on Worm (Driven)	First Intermediate Gear (Driver)	Second Intermediate Gear (Driven)	Gear for Screw (Driver)	Lead of Spiral in Inches	Gear on Worm (Driven)	First Intermediate Gear (Driver)	Second Intermediate Gear (Driven)	Gear for Screw (Driver)
3.175	32	56	40	72	4.040	32	44	40	72	5.185	32	48	56	72
3.189	32	56	48	86	4.059	32	44	48	86	5.209	56	40	32	86
3.198	40	64	44	86	4.070	40	64	56	86	5.226	86	64	28	72
3.241	28	48	40	72	4.074	32	48	44	72	5.238	44	56	48	72
3.256	32	64	56	86	4.093	32	40	44	86	5.316	40	56	64	86
3.267	56	48	28	100	4.134	40	72	64	86	5.333	32	40	48	72
3.300	44	64	48	100	4.144	56	44	28	86	5.347	44	64	56	72
3.307	32	72	64	86	4 167	40	64	48	72	5.357	48	64	40	56
3.333	32	64	48	72	4 200	48	100	56	64	5.412	64	44	32	86
3.349	24	40	48	86	4.242	28	44	48	72	5.426	40	48	56	86
3.360	48	40	28	100	4.252	32	56	64	86	5.444	56	40	28	72
3.383	32	44	40	86	4.264	40	48	44	86	5.568	56	44	28	64
3.403	28	64	56	72	4.286	48	64	32	56	5.625	72	48	24	64
3.411	44	72	48	86	4.341	48	72	56	86	5.657	32	44	56	72
3.422	44	100	56	72	4.364	48	44	40	100	5.714	64	48	24	56
3.429	40	56	48	100	4.365	40	56	44	72	5.759	86	56	24	64
3.488	40	64	48	86	4.375	56	48	24	64	5.788	56	72	64	86
3.492	32	56	44	72	4.385	44	56	48	86	5.833	48	64	56	72
3.500	40	100	56	64	4.444	28	56	64	72	5.847	44	56	64	86
3.520	44	40	32	100	4.465	32	40	48	86	5.893	48	64	44	56
3.551	28	44	48	86	4.477	44	64	56	86	5.920	40	44	56	86
3.565	28	48	44	72	4.480	56	40	32	100	5.926	64	48	32	72
3.581	28	40	44	86	4.537	28	48	56	72	5.954	64	40	32	86
3.618	40	72	56	86	4.548	44	72	64	86	5.969	44	48	56	86
3.636	24	44	48	72	4.558	56	40	28	86	5.972	86	48	24	72
3.654	40	56	44	86	4.583	44	64	48	72	6.061	40	44	48	72
3.667	44	48	40	100	4.667	28	40	48	72	6.109	56	44	48	100
3.704	32	48	40	72	4.736	32	44	56	86	6.125	56	40	28	64
3.721	28	56	64	86	4.762	40	56	48	72	6.136	72	44	24	64
3.733	48	100	56	72	4.773	56	44	24	64	6.140	44	40	48	86
3.750	48	64	28	56	4.821	72	56	24	64	6.160	56	40	44	100
3.771	44	56	48	100	4.848	32	44	48	72	6.202	40	48	64	86
3.798	28	48	56	86	4.861	40	64	56	72	6.222	64	40	28	72
3.810	32	56	48	72	4.884	48	64	56	86	6.234	64	44	24	56
3.819	40	64	44	72	4.889	32	40	44	72	6.349	40	56	64	72
3.837	44	64	48	86	4.949	56	44	28	72	6.364	56	44	32	64
3.840	48	40	32	100	4.961	48	72	64	86	6.379	48	56	64	86
3.850	44	100	56	64	5.074	40	44	48	86	6.429	72	56	32	64
3.889	32	64	56	72	5.080	32	56	64	72	6.465	64	44	32	72
3.907	28	40	48	86	5.093	40	48	44	72	6 481	40	48	56	72
3.920	56	40	28	100	5.104	56	48	28	64	6.515	86	44	24	72
3.979	44	72	56	86	5.119	86	56	24	72	6.563	72	48	28	64
3.986	40	56	48	86	5.133	56	48	44	100	6.667	64	56	28	48

For leads up to 6.667 inches.

GEARING FOR CUTTING WORM AND HELICAL GEARS.—*Continued*

Leads from 6.720 to 12.444 Inches

$$\frac{\text{Lead}}{10} = \frac{\text{Driven}}{\text{Drivers}} = \frac{\text{Second} \times \text{Worm}}{\text{First} \times \text{Screw}}$$

Lead of Spiral in Inches	Gear on Worm (Driven)	First Intermediate Gear (Driver)	Second Intermediate Gear (Driven)	Gear for Screw (Driver)	Lead of Spiral in Inches	Gear on Worm (Driven)	First Intermediate Gear (Driver)	Second Intermediate Gear (Driven)	Gear for Screw (Driver)	Lead of Spiral in Inches	Gear on Worm (Driven)	First Intermediate Gear (Driver)	Second Intermediate Gear (Driven)	Gear for Screw (Driver)
6.720	56	40	48	100	8.212	86	64	44	72	10.238	86	56	48	72
6.750	72	40	24	64	8.250	48	64	44	40	10.286	72	40	32	56
6 765	40	44	64	86	8.312	64	56	32	44	10.313	72	64	44	48
6 806	56	32	28	72	8.333	48	32	40	72	10.370	56	48	64	72
6 822	44	48	64	86	8.361	86	40	28	72	10.390	64	56	40	44
6.825	86	56	32	72	8.377	86	44	24	56	10.419	56	40	64	86
6.968	86	48	28	72	8.485	48	44	56	72	10.451	86	64	56	72
6.984	44	56	64	72	8.532	86	56	40	72	10.476	64	56	44	48
7.000	56	40	32	64	8.551	86	44	28	64	10 500	56	64	48	40
7 013	72	44	24	56	8.555	44	40	56	72	10 558	86	64	44	56
7.071	40	44	56	72	8.571	72	56	32	48	10.667	48	40	64	72
7.104	48	44	56	86	8 682	64	48	56	86	10.694	56	32	44	72
7 111	64	40	32	72	8 687	86	44	32	72	10.714	72	56	40	48
7.130	44	48	56	72	8 839	72	64	44	56	10.750	86	40	32	64
7.159	72	44	28	64	8.889	56	28	32	72	10.859	86	44	40	72
7.163	44	40	56	86	8.930	48	40	64	86	10.909	72	48	32	44
7.167	86	40	24	72	8.958	86	56	28	48	10.938	56	32	40	64
7.273	64	44	28	56	9.000	72	40	28	56	10.949	86	48	44	72
7.292	56	64	40	48	9.143	64	40	32	56	11.111	64	32	40	72
7.330	86	44	24	64	9.166	48	32	44	72	11.168	86	44	32	56
7.333	44	40	48	72	9.214	86	40	24	56	11.169	72	48	64	86
7 407	40	48	64	72	9.333	48	40	56	72	11.198	86	64	40	48
7.465	86	64	40	72	9.351	72	56	32	44	11.250	72	32	28	56
7.500	72	48	32	64	9.375	72	64	40	48	11.313	56	44	64	72
7.601	86	44	28	72	9.385	86	56	44	72	11.402	86	44	28	48
7 619	48	56	64	72	9.406	86	40	28	64	11.518	86	64	48	56
7.679	86	64	32	56	9.429	48	56	44	40	11.667	56	32	48	72
7.714	72	40	24	56	9.471	56	44	64	86	11.688	72	56	40	44
7.778	64	32	28	72	9.524	64	56	40	48	11.758	86	32	28	64
7.814	48	40	56	86	9.545	72	48	28	44	11.786	72	56	44	48
7.839	86	48	28	64	9.556	86	40	32	72	11.852	64	24	32	72
7.875	72	40	28	64	9.568	72	56	64	86	12.000	72	40	32	48
7.955	56	64	40	44	9 598	86	64	40	56	12.031	56	32	44	04
7.963	86	48	32	72	9.625	56	64	44	40	12.040	86	56	64	72
8 000	64	40	28	56	9.643	72	64	48	56	12.121	64	48	40	44
8.021	56	64	44	48	9.697	64	48	32	44	12.178	72	44	64	86
8.036	72	64	40	56	9.722	56	32	40	72	12.216	86	64	40	44
8.063	86	40	24	64	9.773	86	44	32	64	12.222	48	24	44	72
8.081	40	44	64	72	9.778	44	40	64	72	12.273	72	64	48	44
8.118	48	44	64	86	9.844	72	32	28	64	12.286	86	40	32	56
8.148	44	48	64	72	9.954	86	48	40	72	12.318	86	64	44	48
8.182	72	44	28	56	10.159	64	28	32	72	12.375	72	40	44	64
8.186	44	40	64	86	10.227	72	64	40	44	12.444	56	40	64	72

For leads up to 12.444.

GEARING FOR CUTTING WORM AND HELICAL GEARS—*Continued*

Leads from 12.468 to 24.635 Inches

$$\frac{\text{Lead}}{10} = \frac{\text{Driven}}{\text{Drivers}} = \frac{\text{Second} \times \text{Worm}}{\text{First} \times \text{Screw}}$$

Lead of Spiral in Inches	Gear on Worm (Driven)	First Intermediate Gear (Driver)	Second Intermediate Gear (Driven)	Gear for Screw (Driver)	Lead of Spiral in Inches	Gear on Worm (Driven)	First Intermediate Gear (Driver)	Second Intermediate Gear (Driven)	Gear for Screw (Driver)	Lead of Spiral in Inches	Gear on Worm (Driven)	First Intermediate Gear (Driver)	Second Intermediate Gear (Driven)	Gear for Screw (Driver)
12.468	64	56	48	44	15.429	72	56	48	40	19.196	86	32	40	56
12.500	56	28	40	64	15 469	72	32	44	64	19.286	72	32	48	56
12.542	86	40	28	48	15.556	64	32	56	72	19.592	64	28	48	56
12.571	64	56	44	40	15.636	86	40	32	44	19.636	72	44	48	40
12 698	64	28	40	72	15.677	86	64	56	48	19.688	72	32	56	64
12.798	86	56	40	48	15.714	64	32	44	56	19.708	86	48	44	40
12 833	56	48	44	40	15.750	72	64	56	40	19.907	86	24	40	72
12.857	72	28	32	64	15.926	86	48	64	72	20.156	86	64	72	48
12.963	56	24	40	72	16.071	72	32	40	56	20.204	72	28	44	56
13.030	86	48	32	44	16.125	86	64	48	40	20.364	64	44	56	40
13.091	72	40	32	44	16.288	86	48	40	44	20.455	72	32	40	44
13.125	56	32	48	64	16.296	64	24	44	72	20.476	86	56	64	48
13.139	86	40	44	72	16.424	86	32	44	72	20.571	72	56	64	40
13.333	64	32	48	72	16.500	72	48	44	40	20.625	72	48	44	32
13.395	72	40	64	86	16.722	86	40	56	72	20.741	64	24	56	72
13.438	86	32	28	56	16.753	86	56	48	44	29.903	86	32	56	72
13.500	72	64	48	40	16.797	86	32	40	64	20.952	64	24	44	56
13.636	72	48	40	44	16.875	72	32	48	64	21.000	72	48	56	40
13.651	86	28	32	72	16.893	86	56	44	40	21.116	86	32	44	56
13.714	64	56	48	40	16.970	64	48	56	44	21.429	72	28	40	48
13.750	56	28	44	64	17.063	86	28	40	72	21.818	72	48	64	44
13.935	86	24	28	72	17.102	86	64	56	44	21.939	86	28	40	56
13.961	86	56	40	44	17.143	72	56	64	48	21.989	86	64	72	44
13.968	64	28	44	72	17.277	86	64	72	56	22.041	72	28	48	56
14.026	72	56	48	44	17.374	86	44	64	72	22.338	86	56	64	44
14 063	72	32	40	64	17.455	64	44	48	40	22.396	86	32	40	48
14.077	86	56	44	48	17.500	56	24	48	64	22.500	72	28	56	64
14.143	72	56	44	40	17.551	86	28	32	56	22.803	86	48	56	44
14.259	56	24	44	72	17.679	72	56	44	32	22.857	64	24	48	56
14.286	64	32	40	56	17.777	64	28	56	72	22.909	72	44	56	40
14.318	72	64	56	44	17.917	86	32	48	72	23.036	86	56	72	48
14.333	86	40	48	72	17.959	64	28	44	56	23.333	64	48	56	32
14.659	86	64	48	44	18.333	64	48	44	32	23.455	86	44	48	40
14.667	64	48	44	40	18.367	72	28	40	56	23.516	86	64	56	32
14.694	72	28	32	56	18.429	86	56	48	40	23.571	72	28	44	48
14.781	86	64	44	40	18.477	86	32	44	64	23.889	86	32	64	72
14.815	64	24	40	72	18.667	64	48	56	40	24.000	72	48	64	40
14.931	86	32	40	72	18.701	72	56	64	44	24.133	86	28	44	56
15.000	56	28	48	64	18.750	72	32	40	48	24.188	86	64	72	40
15.202	86	44	56	72	18.770	86	28	44	72	24.432	86	32	40	44
5.238	64	28	48	72	18.813	86	64	56	40	24.545	72	44	48	32
15.273	56	44	48	40	19.091	72	48	56	44	24.571	86	56	64	40
15.357	86	28	32	64	19.111	86	40	64	72	24.635	86	48	44	32

For leads up to 24.635 inches.

GEARING FOR CUTTING WORM AND HELICAL GEARS.—*Continued*

Leads from 24.750 to 80.625 Inches

$$\frac{\text{Lead}}{10} = \frac{\text{Driven}}{\text{Drivers}} = \frac{\text{Second} \times \text{Worm}}{\text{First} \times \text{Screw}}$$

Lead of Spiral in Inches	Gear on Worm (Driven)	First Intermediate Gear (Driver)	Second Intermediate Gear (Driven)	Gear for Screw (Driver)	Lead of Spiral in Inches	Gear on Worm (Driven)	First Intermediate Gear (Driver)	Second Intermediate Gear (Driven)	Gear for Screw (Driver)	Lead of Spiral in Inches	Gear on Worm (Driven)	First Intermediate Gear (Driver)	Second Intermediate Gear (Driven)	Gear for Screw (Driver)
24.750	72	40	44	32	30.857	72	28	48	40	40.952	86	28	64	48
25.083	86	48	56	40	31.111	64	24	56	48	41.143	72	28	64	40
25.130	86	56	72	44	31.273	86	44	64	40	41.806	86	24	56	48
25.455	64	44	56	32	31.354	86	48	56	32	42.232	86	28	44	32
25.595	86	28	40	48	31.500	72	40	56	32	43.000	86	40	64	32
25.714	72	56	64	32	31.852	86	24	64	72	43.636	72	24	64	44
26.061	86	48	64	44	32.000	64	28	56	40	43.977	86	44	72	32
26.182	72	44	64	40	32.250	86	48	72	40	44.675	86	28	64	44
26.250	72	48	56	32	32.576	86	24	40	44	45.000	72	28	56	32
26.327	86	28	48	56	32.727	72	44	64	32	45.606	86	24	56	44
26.667	64	28	56	48	32.847	86	24	44	48	46.071	86	28	72	48
26.875	86	28	56	64	33.507	86	28	48	44	47.778	86	24	64	48
27.000	72	40	48	32	33.786	86	28	44	40	48.000	72	24	64	40
27.302	86	28	64	72	33.939	64	24	56	44	48.375	86	40	72	32
27.364	86	44	56	40	34.205	86	44	56	32	49.143	86	28	64	40
27.500	72	24	44	48	34.286	72	28	64	48	50.167	86	24	56	40
27.643	86	56	72	40	34.554	86	56	72	32	50.260	86	28	72	44
27.922	86	28	40	44	35.000	72	24	56	48	51.429	72	28	64	32
28.000	64	40	56	32	35.102	86	28	64	56	52.121	86	24	64	44
28.052	72	28	48	44	35.182	86	44	72	40	53.750	86	28	56	32
28.155	86	28	44	48	35.833	86	48	64	32	55.286	86	28	72	40
28.636	72	44	56	32	36.000	72	40	64	32	57.333	86	24	64	40
28.667	86	48	64	40	36.857	86	28	48	40	58.636	86	24	72	44
29.091	64	28	56	44	37.403	72	28	64	44	60.000	72	24	64	32
29.318	86	48	72	44	37.625	86	40	56	32	61.429	86	28	64	32
29.388	72	28	64	56	38.182	72	24	56	44	62.708	86	24	56	32
29.563	86	40	44	32	39.091	86	44	64	32	64.500	86	24	72	40
29.861	86	24	40	48	39.417	86	24	44	40	69.107	86	28	72	32
30.000	72	48	64	32	39.490	86	28	72	56	71.667	86	24	64	32
30.234	86	64	72	32	40.000	72	24	64	48	80.625	86	24	72	32
30.714	86	56	64	32	40.313	86	48	72	32					

For leads up to 80.625 inches.

BROWN AND SHARPE DIVIDING HEAD—TABLE OF GEARS AND INDEX PLATES

Gears: 24 (2) 28, 32, 40, 44, 48, 56, 64, 72, 86, 100 teeth.

Index plates: Number of holes in circles:

No. 1: 15, 16, 17, 18, 19, 20 holes.
No. 2. 21, 23, 27, 29, 31, 33 holes.
No. 3, 37, 39, 41, 43, 47, 49 holes.

PLAIN AND DIFFERENTIAL INDEXING ON BROWN AND SHARPE MILLING MACHINES

The general arrangement of the universal dividing head is illustrated in Figs. 23 to 25. As indicated by the diagrammatic sketch, Fig. 24, the worm wheel *A* is secured to the main spindle of the spiral head and rotated by means of the worm shaft and single-threaded worm *B*. The index plate (having rows of equally spaced holes) remains stationary during the dividing operation and is fitted with adjustable sector arms which obviate the necessity of counting the number of holes through which the index crank must be moved each time a division is made on the surface of the work. The standard ratio between the worm *B* and the worm wheel *A* is 1:40; and to find the movement of the index crank or any required division, the following formula is employed: The movement of the index crank $= \frac{40}{N}$, where *N* is the number of equal divisions required.

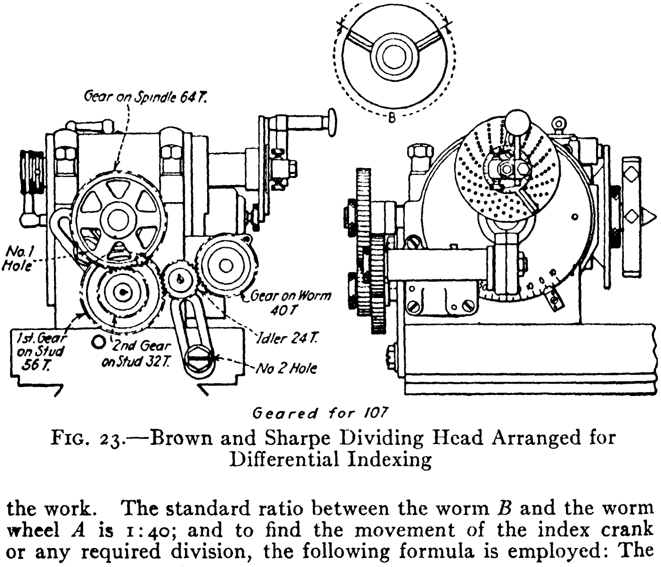


FIG. 23.—Brown and Sharpe Dividing Head Arranged for Differential Indexing

EXAMPLE.—Let it be required to divide the circumference of a piece of work into 48 equal parts.

The movement of the index crank for each division $= \frac{40}{48} = \frac{5}{6}$ revolutions.

An index plate having a row of 18 holes would be chosen and the sector arms set to limit the movement of the index crank to 15 spaces for $\frac{5}{6} = \frac{15}{18}$.

Plain or simple indexing is obtained directly by using the index plate and does not make use of the gearing shown in Fig. 23.

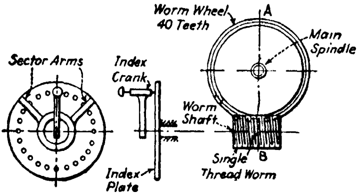


FIG. 24.

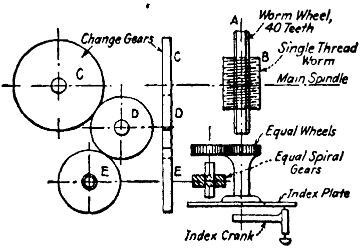


FIG. 25.

General Principle of Differential Indexing

The number of equal divisions which may be obtained by simple indexing (with the index plates usually provided by milling-machine makers) is strictly limited, and does not meet all the requirements called for in practice.

Differential indexing provides the most convenient way of overcoming this difficulty, this method being simpler than compound indexing. In the differential system the dividing operation is performed as in simple indexing, the only difference being that the index plate instead of remaining stationary during the process of indexing, is made to move relatively to the index crank. The index plate is connected to the main spindle of the index head by a set of change gears, which may be arranged to give either a *positive* or *negative* movement to the index plate; whichever is found necessary to determine the *actual* motion which must be given to the index crank in order to satisfy the formula given above for simple indexing: Actual movement of the index crank $= \frac{40}{N}$.

The two views in Fig. 14 and the diagram in Fig. 16 will serve to give an idea of the arrangement of the gearing, which is adopted in differential indexing.

For any movement of the index crank the motion is transmitted to the index plate (which is free to rotate on the worm shaft) as follows: The index crank drives through the worm shaft and worm *B* to the worm wheel *A*, which in turn transmits the motion through the change gears, spiral gears, and equal gears, the last of which is connected directly to the index plate. The last pair of gears being equal and driven through equal spiral gears, whatever number of revolutions are given to the gear *E*, the index plate will make the same number. It is therefore convenient to consider the revolutions of the gear *E* as the revolutions of the index plate in all calculations.

To illustrate the influence of the gearing on the index plate and indexing operation, consider the following example: Required to index for 107 divisions:

If we use the plate having 20 holes and move 8 holes per division, as in simple indexing for 100 divisions, 100 moves will of course be required to rotate the worm 40 turns, which in turn rotates the spindle once. If now we make 107 moves with the index plate fixed as in simple indexing, we will obtain $107 \times \frac{8}{20} = 42.8$ revolutions of the worm, which is 2.8 in excess of what is required. Therefore, the index plate must be geared so that it will move back 2.8 turns while the spindle is revolving once; that is, the ratio of the gearing must be 2.8:1.

$$\frac{2.8}{1} = \frac{2.8}{2} \times \frac{2}{1}$$

$$\frac{2.8}{2} \times \frac{20}{20} = \frac{56}{40} \qquad \frac{2}{1} \times \frac{32}{32} = \frac{64}{32}$$

Then $\frac{2.8}{1} = \frac{56}{40} \times \frac{64}{32}$, and the gears will be 64 and 56 for the spindle and first gear on stud and 40 and 32 for the worm and second gear on stud, as shown in Fig. 23. As compound gears are used, but one idler is required to cause the index plate to move in a direction opposite to that of the crank. For this purpose an idler having 24 teeth is employed.

Formula for Finding the Gear Ratio

A simple formula for the determination of the gear ratio necessary to rotate the index plate as required for any given number of teeth is derived as follows:

Let N equal the number of divisions required to be indexed.

Let n equal some number either greater or smaller than N, which can be obtained directly by simple indexing.

Let $\frac{40}{n}$ equal the index setting, that is, the setting of the sector arms for each movement of the index crank;

Then $(n - N) \times \frac{40}{n}$ equals the gear ratio.

If the number chosen for n is greater than the number of divisions required (N) the index plate must be geared to have a positive motion, that is, to rotate in the same direction as the index crank.

If the number n is less than N, the index plate is geared to have a negative motion, that is, to rotate in opposite direction to the crank.

Application of the Formula

Suppose we wish to obtain 63 divisions. Choose any number for n which may be obtained by simple indexing, say 60, then

$$(n - N) = (60 - 63) = -3$$

This number (-3), when multiplied by the value of the index setting, will give the gear ratio. The index setting $= \frac{40}{n}, = \frac{40}{60},$ then

$(n - N)\frac{40}{n} = -3 \times \frac{40}{60} = -\frac{60}{30}$ or $\frac{2}{1}$, as the gear ratio.

We can, therefore, use gears of 48 and 24 teeth, the 48 gear being the driver, and the 24 gear, the follower; that is, the 48 gear being on the spindle, and the 24 gear on the worm. As n is smaller than N, the idlers are arranged to give a negative movement to the index plate.

The index setting is found above as $\frac{40}{n}$ which equals $\frac{40}{60}$ or $\frac{2}{3}$. We can thus use the 39-hole circle in the index plate and set the sector for 26 holes, giving the setting as $\frac{26}{39}$ or $\frac{2}{3}$; that is, we set the sector and index pin exactly the same as for simple indexing of 60 divisions.

The tables on the following pages give the dividing-head gears for indexing all numbers up to 730.

Number of Divisions	Index Circle	No. of Turns of Index	Gear on Worm	No. 1 Hole		Gear on Spindle	Idlers	
				First Gear on Stud	Second Gear on Stud		No. 1 Hole	No. 2 Hole
2	Any	20						
3	39	$13\frac{13}{39}$						
4	Any	10						
5	Any	8						
6	39	$6\frac{26}{39}$						
7	49	$5\frac{35}{49}$						
8	Any	5						
9	27	$4\frac{12}{27}$						
10	Any	4						
11	33	$3\frac{21}{33}$						
12	39	$3\frac{13}{39}$						
13	39	$3\frac{3}{39}$						
14	49	$2\frac{42}{49}$						
15	39	$2\frac{26}{39}$						
16	20	$2\frac{10}{20}$						
17	17	$2\frac{6}{17}$						
18	27	$2\frac{6}{27}$						
19	19	$2\frac{2}{19}$						
20	Any	2						
21	21	$1\frac{19}{21}$						
22	33	$1\frac{27}{33}$						
23	23	$1\frac{17}{23}$						
24	39	$1\frac{26}{39}$						
25	20	$1\frac{12}{20}$						
26	39	$1\frac{21}{39}$						
27	27	$1\frac{13}{27}$						
28	49	$1\frac{21}{49}$						
29	29	$1\frac{11}{29}$						
30	39	$1\frac{13}{39}$						
31	31	$1\frac{9}{31}$						
32	20	$1\frac{5}{20}$						
33	33	$1\frac{7}{33}$						
34	17	$1\frac{8}{17}$						
35	49	$1\frac{7}{49}$						
36	27	$1\frac{8}{27}$						
37	37	$1\frac{3}{37}$						
38	19	$1\frac{1}{19}$						
39	39	$1\frac{1}{39}$						
40	Any	1						
41	41	$\frac{40}{41}$						
42	21	$\frac{20}{21}$						

Number of Divisions	Index Circle	No. of Turns of Index	Gear on Worm	No. 1 Hole		Gear on Spindle	Idlers	
				First Gear on Stud	Second Gear on Stud		No. 1 Hole	No. 2 Hole
43	43	40/43						
44	33	30/33						
45	27	24/27						
46	23	20/23						
47	47	40/47						
48	18	15/18						
49	49	40/49						
50	20	16/20						
51	17	14/17	24			48	24	44
52	39	30/39						
53	49	35/49	56	40	24	72		
54	27	20/27						
55	33	24/33						
56	49	35/49						
57	21	15/21	56			40	24	44
58	29	20/29						
59	39	28/39	48			32	44	
60	39	26/39						
61	39	26/39	48			32	24	44
62	31	20/31						
63	39	26/39	24			48	24	44
64	16	10/16						
65	39	24/39						
66	33	20/33						
67	21	12/21	28			48	44	
68	17	10/17						
69	20	12/20	40			56	24	44
70	49	28/49						
71	18	10/18	72			40	24	
72	27	15/27						
73	21	12/21	28			48	24	44
74	37	20/37						
75	15	8/15						
76	19	10/19						
77	20	10/20	32			48	44	
78	39	20/39						
79	20	10/20	48			24	44	
80	20	10/20						
81	20	10/20	48			24	24	44
82	41	20/41						
83	20	10/20	32			48	24	44

Number of Divisions	Index Circle	No. of Turns of Index	Gear on Worm	No. 1 Hole		Gear on Spindle	Idlers	
				First Gear on Stud	Second Gear on Stud		No. 1 Hole	No. 2 Hole
84	21	$\frac{10}{21}$						
85	17	$\frac{8}{17}$						
86	43	$\frac{20}{43}$						
87	15	$\frac{7}{15}$	40			24	24	44
88	33	$\frac{15}{33}$						
89	18	$\frac{8}{18}$	72			32	44	
90	27	$\frac{12}{27}$						
91	39	$\frac{18}{39}$	24			48	24	44
92	23	$\frac{10}{23}$						
93	18	$\frac{8}{18}$	24			32	24	44
94	47	$\frac{20}{47}$						
95	19	$\frac{8}{19}$						
96	21	$\frac{9}{21}$	28			32	24	44
97	20	$\frac{8}{20}$	40			48	44	
98	49	$\frac{20}{49}$						
99	20	$\frac{8}{20}$	56	28	40	32		
100	20	$\frac{8}{20}$						
101	20	$\frac{8}{20}$	72	24	40	48		24
102	20	$\frac{8}{20}$	40			32	24	44
103	20	$\frac{8}{20}$	40			48	24	44
104	39	$\frac{15}{39}$						
105	21	$\frac{8}{21}$						
106	43	$\frac{16}{43}$	86	24	24	48		
107	20	$\frac{8}{20}$	40	56	32	64		24
108	27	$\frac{10}{27}$						
109	16	$\frac{6}{16}$	32			28	24	44
110	33	$\frac{12}{33}$						
111	39	$\frac{18}{39}$	24			72	32	
112	39	$\frac{18}{39}$	24			64	44	
113	39	$\frac{18}{39}$	24			56	44	
114	39	$\frac{18}{39}$	24			48	44	
115	23	$\frac{8}{23}$						
116	29	$\frac{10}{29}$						
117	39	$\frac{18}{39}$	24			24	56	
118	39	$\frac{18}{39}$	48			32	44	
119	39	$\frac{18}{39}$	72			24	44	
120	39	$\frac{18}{39}$						
121	39	$\frac{18}{39}$	72			24	24	44
122	39	$\frac{18}{39}$	48			32	24	44
123	39	$\frac{18}{39}$	24			24	24	44
124	31	$\frac{10}{31}$						

Number of Divisions	Index Circle	No. of Turns of Index	Gear on Worm	No. 1 Hole		Gear on Spindle	Idlers	
				First Gear on Stud	Second Gear on Stud		No. 1 Hole	No. 2 Hole
125	39	$\frac{18}{39}$	24			40	24	44
126	39	$\frac{18}{39}$	24			48	24	44
127	39	$\frac{18}{39}$	24			56	24	44
128	16	$\frac{5}{16}$						
129	39	$\frac{13}{39}$	24			72	24	44
130	39	$\frac{12}{39}$						
131	20	$\frac{6}{20}$	40			28	44	
132	33	$\frac{10}{33}$						
133	21	$\frac{6}{21}$	24			48	44	
134	21	$\frac{6}{21}$	28			48	44	
135	27	$\frac{8}{27}$						
136	17	$\frac{5}{17}$						
137	21	$\frac{6}{21}$	28			24	56	
138	21	$\frac{6}{21}$	56			32	44	
139	21	$\frac{6}{21}$	56	32	48	24		
140	49	$\frac{14}{49}$						
141	18	$\frac{5}{18}$	48			40	44	
142	21	$\frac{6}{21}$	56			32	24	44
143	21	$\frac{6}{21}$	28			24	24	44
144	18	$\frac{5}{18}$						
145	29	$\frac{8}{29}$						
146	21	$\frac{6}{21}$	28			48	24	44
147	21	$\frac{6}{21}$	24			48	24	44
148	37	$\frac{10}{37}$						
149	21	$\frac{6}{21}$	28			72	24	44
150	15	$\frac{4}{15}$						
151	20	$\frac{5}{20}$	32			72	44	
152	19	$\frac{5}{19}$						
153	20	$\frac{5}{20}$	32			56	44	
154	20	$\frac{5}{20}$	32			48	44	
155	31	$\frac{8}{31}$						
156	39	$\frac{10}{39}$						
157	20	$\frac{5}{20}$	32			24	56	
158	20	$\frac{5}{20}$	48			24	44	
159	20	$\frac{5}{20}$	64	32	56	28		
160	20	$\frac{5}{20}$						
161	20	$\frac{5}{20}$	64	32	56	28		24
162	20	$\frac{5}{20}$	48			24	24	44
163	20	$\frac{5}{20}$	32			24	24	44
164	41	$\frac{10}{41}$						
165	33	$\frac{8}{33}$						

Number of Divisions	Index Circle	No. of Turns of Index	Gear on Worm	No. 1 Hole		Gear on Spindle	Idlers	
				First Gear on Stud	Second Gear on Stud		No. 1 Hole	No. 2 Hole
166	20	$\frac{5}{20}$	32			48	24	44
167	20	$\frac{5}{20}$	32			56	24	44
168	21	$\frac{5}{21}$						
169	20	$\frac{5}{20}$	32			72	24	44
170	17	$\frac{4}{17}$						
171	21	$\frac{5}{21}$	56			40	24	44
172	43	$\frac{10}{43}$						
173	18	$\frac{4}{18}$	72	56	32	64		
174	18	$\frac{4}{18}$	24			32	56	
175	18	$\frac{4}{18}$	72	40	32	64		
176	18	$\frac{4}{18}$	72	24	24	64		
177	18	$\frac{4}{18}$	72			48	24	
178	18	$\frac{4}{18}$	72			32	44	
179	18	$\frac{4}{18}$	72	24	48	32		
180	18	$\frac{4}{18}$						
181	18	$\frac{4}{18}$	72	24	48	32		24
182	18	$\frac{4}{18}$	72			32	24	44
183	18	$\frac{4}{18}$	48			32	24	44
184	23	$\frac{5}{23}$						
185	37	$\frac{8}{37}$						
186	18	$\frac{4}{18}$	48			64	24	44
187	18	$\frac{4}{18}$	72	48	24	56		24
188	47	$\frac{10}{47}$						
189	18	$\frac{4}{18}$	32			64	24	44
190	19	$\frac{4}{19}$						
191	20	$\frac{4}{20}$	40			72	24	
192	20	$\frac{4}{20}$	40			64	44	
193	20	$\frac{4}{20}$	40			56	44	
194	20	$\frac{4}{20}$	40			48	44	
195	39	$\frac{8}{39}$						
196	49	$\frac{10}{49}$						
197	20	$\frac{4}{20}$	40			24	56	
198	20	$\frac{4}{20}$	56	28	40	32		
199	20	$\frac{4}{20}$	100	40	64	32		
200	20	$\frac{4}{20}$						
201	20	$\frac{4}{20}$	72	24	40	24		24
202	20	$\frac{4}{20}$	72	24	40	48		24
203	20	$\frac{4}{20}$	40			24	24	44
204	20	$\frac{4}{20}$	40			32	24	44
205	41	$\frac{8}{41}$						
206	20	$\frac{4}{20}$	40			48	24	44

Number of Divisions	Index Circle	No. of Turns of Index	Gear on Worm	No. 1 Hole		Gear on Spindle	Idlers	
				First Gear on Stud	Second Gear on Stud		No. 1 Hole	No. 2 Hole
207	20	$\frac{4}{20}$	40			56	24	44
208	20	$\frac{4}{20}$	40			64	24	44
209	20	$\frac{4}{20}$	40			72	24	44
210	21	$\frac{4}{21}$						
211	16	$\frac{3}{16}$	64			28	44	
212	43	$\frac{8}{43}$	86	24	24	48		
213	27	$\frac{5}{27}$	72			40	44	
214	20	$\frac{4}{20}$	40	56	32	64		24
215	43	$\frac{8}{43}$						
216	27	$\frac{5}{27}$						
217	21	$\frac{4}{21}$	48			64	24	44
218	16	$\frac{3}{16}$	64			56	24	44
219	21	$\frac{4}{21}$	28			48	24	44
220	33	$\frac{6}{33}$						
221	17	$\frac{3}{17}$	24			24	56	
222	18	$\frac{3}{18}$	24			72	44	
223	43	$\frac{8}{43}$	86	48	24	64		24
224	18	$\frac{3}{18}$	24			64	44	
225	27	$\frac{5}{27}$	24			40	24	44
226	18	$\frac{3}{18}$	24			56	44	
227	49	$\frac{8}{49}$	56	64	28	72		
228	18	$\frac{3}{18}$	24			48	44	
229	18	$\frac{3}{18}$	24			44	48	
230	23	$\frac{4}{23}$						
231	18	$\frac{3}{18}$	32			48	44	
232	29	$\frac{5}{29}$						
233	18	$\frac{3}{18}$	48			56	44	
234	18	$\frac{3}{18}$	24			24	56	
235	47	$\frac{8}{47}$						
236	18	$\frac{3}{18}$	48			32	44	
237	18	$\frac{3}{18}$	48			24	44	
238	18	$\frac{3}{18}$	72			24	44	
239	18	$\frac{3}{18}$	72	24	64	32		
240	18	$\frac{3}{18}$						
241	18	$\frac{3}{18}$	72	24	64	32		24
242	18	$\frac{3}{18}$	72			24	24	44
243	18	$\frac{3}{18}$	64			32	24	44
244	18	$\frac{3}{18}$	48			32	24	44
245	49	$\frac{8}{49}$						
246	18	$\frac{3}{18}$	24			24	24	44
247	18	$\frac{3}{18}$	48			56	24	44

Number of Divisions	Index Circle	No. of Turns of Index	Gear on Worm	No. 1 Hole		Gear on Spindle	Idlers	
				First Gear on Stud	Second Gear on Stud		No. 1 Hole	No. 2 Hole
248	31	$\frac{5}{31}$						
249	18	$\frac{3}{18}$	32			48	24	44
250	18	$\frac{3}{18}$	24			40	24	44
251	18	$\frac{3}{18}$	48	44	32	64		24
252	18	$\frac{3}{18}$	24			48	24	44
253	33	$\frac{5}{33}$	24			40	56	
254	18	$\frac{3}{18}$	24			56	24	44
255	18	$\frac{3}{18}$	48	40	24	72		24
256	18	$\frac{3}{18}$	24			64	24	44
257	49	$\frac{8}{49}$	56	48	28	64		24
258	43	$\frac{7}{43}$	32			64	24	44
259	21	$\frac{3}{21}$	24			72	44	
260	39	$\frac{6}{39}$						
261	29	$\frac{4}{29}$	48	64	24	72		
262	20	$\frac{3}{20}$	40			28	44	
263	49	$\frac{8}{49}$	56	64	28	72		24
264	33	$\frac{5}{33}$						
265	21	$\frac{3}{21}$	56	40	24	72		
266	21	$\frac{3}{21}$	32			64	44	
267	27	$\frac{4}{27}$	72			32	44	
268	21	$\frac{3}{21}$	28			48	44	
269	20	$\frac{3}{20}$	64	32	40	28		24
270	27	$\frac{4}{27}$						
271	21	$\frac{3}{21}$	56			72	24	
272	21	$\frac{3}{21}$	56			64	24	
273	21	$\frac{3}{21}$	24			24	56	
274	21	$\frac{3}{21}$	56			48	44	
275	21	$\frac{3}{21}$	56			40	44	
276	21	$\frac{3}{21}$	56			32	44	
277	21	$\frac{3}{21}$	56			24	44	
278	21	$\frac{3}{21}$	56	32	48	24		
279	27	$\frac{4}{27}$	24			32	24	44
280	49	$\frac{7}{49}$						
281	21	$\frac{3}{21}$	72	24	56	24		24
282	43	$\frac{6}{43}$	86	24	24	56		
283	21	$\frac{3}{21}$	56			24	24	44
284	21	$\frac{3}{21}$	56			32	24	44
285	21	$\frac{3}{21}$	56			40	24	44
286	21	$\frac{3}{21}$	56			48	24	44
287	21	$\frac{3}{21}$	24			24	24	44
288	21	$\frac{3}{21}$	28			32	24	44

Number of Divisions	Index Circle	No. of Turns of Index	Gear on Worm	No. 1 Hole		Gear on Spindle	Idlers	
				First Gear on Stud	Second Gear on Stud		No. 1 Hole	No. 2 Hole
289	21	$\frac{8}{21}$	56			72	24	44
290	29	$\frac{4}{29}$						
291	15	$\frac{2}{15}$	40			48	44	
292	21	$\frac{8}{21}$	28			48	24	44
293	15	$\frac{2}{15}$	48	32	40	56		
294	21	$\frac{8}{21}$	24			48	24	44
295	15	$\frac{2}{15}$	48			32	44	
296	37	$\frac{5}{37}$						
297	33	$\frac{4}{33}$	28	48	24	56		
298	21	$\frac{8}{21}$	28			72	24	44
299	23	$\frac{3}{23}$	24			24	56	
300	15	$\frac{2}{15}$						
301	43	$\frac{6}{43}$	24			48	24	44
302	16	$\frac{2}{16}$	32			72	24	
303	15	$\frac{2}{15}$	72	24	40	48		24
304	16	$\frac{2}{16}$	24			48	44	
305	15	$\frac{2}{15}$	48			32	24	44
306	15	$\frac{2}{15}$	40			32	24	44
307	15	$\frac{2}{15}$	72	48	40	56		24
308	16	$\frac{2}{16}$	32			48	44	
309	15	$\frac{2}{15}$	40			48	24	44
310	31	$\frac{4}{31}$						
311	16	$\frac{2}{16}$	64	24	24	72		
312	39	$\frac{5}{39}$						
313	16	$\frac{2}{16}$	32			28	56	
314	16	$\frac{2}{16}$	32			24	56	
315	16	$\frac{2}{16}$	64			40	24	
316	16	$\frac{2}{16}$	64			32	44	
317	16	$\frac{2}{16}$	64			24	44	
318	16	$\frac{2}{16}$	56	28	48	24		
319	29	$\frac{4}{29}$	48	64	24	72		24
320	16	$\frac{2}{16}$						
321	16	$\frac{2}{16}$	72	24	64	24		24
322	23	$\frac{8}{23}$	32			64	24	44
323	16	$\frac{2}{16}$	64			24	24	44
324	16	$\frac{2}{16}$	64			32	24	44
325	16	$\frac{2}{16}$	64			40	24	44
326	16	$\frac{2}{16}$	32			24	24	44
327	16	$\frac{2}{16}$	32			28	24	44
328	41	$\frac{5}{41}$						
329	16	$\frac{2}{16}$	64	24	24	72		24

Number of Divisions	Index Circle	No. of Turns of Index	Gear on Worm	No. 1 Hole		Gear on Spindle	Idlers	
				First Gear on Stud	Second Gear on Stud		No. 1 Hole	No. 2 Hole
330	33	$\frac{4}{33}$						
331	16	$\frac{2}{16}$	64	44	24	48		24
332	16	$\frac{2}{16}$	32			48	24	44
333	18	$\frac{2}{18}$	24			72	44	
334	16	$\frac{2}{16}$	32			56	24	44
335	33	$\frac{4}{33}$	72	48	44	40		24
336	16	$\frac{2}{16}$	32			64	24	44
337	43	$\frac{5}{43}$	86	40	32	56		
338	16	$\frac{2}{16}$	32			72	24	44
339	18	$\frac{2}{18}$	24			56	44	
340	17	$\frac{2}{17}$						
341	43	$\frac{5}{43}$	86	24	32	40		
342	18	$\frac{2}{18}$	32			64	44	
343	15	$\frac{2}{15}$	40	64	24	86		24
344	43	$\frac{5}{43}$						
345	18	$\frac{2}{18}$	24			40	56	
346	18	$\frac{2}{18}$	72	56	32	64		
347	43	$\frac{5}{43}$	86	24	32	40		24
348	18	$\frac{2}{18}$	24			32	56	
349	18	$\frac{2}{18}$	72	44	24	48		
350	18	$\frac{2}{18}$	72	40	32	64		
351	18	$\frac{2}{18}$	24			24	56	
352	18	$\frac{2}{18}$	72	24	24	64		
353	18	$\frac{2}{18}$	72			56	24	
354	18	$\frac{2}{18}$	72			48	24	
355	18	$\frac{2}{18}$	72			40	24	
356	18	$\frac{2}{18}$	72			32	24	
357	18	$\frac{2}{18}$	72			24	44	
358	18	$\frac{2}{18}$	72	32	48	24		
359	43	$\frac{5}{43}$	86	48	32	100		24
360	18	$\frac{2}{18}$						
361	19	$\frac{2}{19}$	32			64	44	
362	18	$\frac{2}{18}$	72	28	56	32		24
363	18	$\frac{2}{18}$	72			24	24	44
364	18	$\frac{2}{18}$	72			32	24	44
365	20	$\frac{2}{20}$	32	48	24	56		
366	18	$\frac{2}{18}$	48			32	24	44
367	18	$\frac{2}{18}$	72			56	24	24
368	18	$\frac{2}{18}$	72	24	24	64		24
369	41	$\frac{4}{41}$	32	56	28	64		
370	37	$\frac{4}{37}$						

Number of Divisions	Index Circle	No. of Turns of Index	Gear on Worm	No. 1 Hole		Gear on Spindle	Idlers	
				First Gear on Stud	Second Gear on Stud		No. 1 Hole	No. 2 Hole
371	21	$\frac{2}{21}$	32	56	24	64		
372	18	$\frac{2}{18}$	48			64	24	44
373	20	$\frac{2}{20}$	40	48	32	72		
374	18	$\frac{2}{18}$	72	64	32	56		24
375	18	$\frac{2}{18}$	24			40	24	44
376	47	$\frac{5}{47}$						
377	29	$\frac{3}{29}$	24			24	56	
378	18	$\frac{2}{18}$	32			64	24	44
379	20	$\frac{2}{20}$	48	56	40	72		
380	19	$\frac{2}{19}$						
381	18	$\frac{2}{18}$	24			56	24	44
382	20	$\frac{2}{20}$	40			72	24	
383	20	$\frac{2}{20}$	40			68 [1]	44	
384	20	$\frac{2}{20}$	40			64	44	
385	20	$\frac{2}{20}$	32			48	44	
386	20	$\frac{2}{20}$	40			56	44	
387	43	$\frac{4}{43}$	32	56	28	64		
388	20	$\frac{2}{20}$	40			48	44	
389	20	$\frac{2}{20}$	40			44	56	
390	39	$\frac{4}{39}$						
391	20	$\frac{2}{20}$	48	24	40	72		
392	49	$\frac{5}{49}$						
393	20	$\frac{2}{20}$	40			28	44	
394	20	$\frac{2}{20}$	40			24	56	
395	20	$\frac{2}{20}$	64			32	44	
396	20	$\frac{2}{20}$	56	28	40	32		
397	20	$\frac{2}{20}$	64	24	40	32		
398	20	$\frac{2}{20}$	100	40	64	32		
399	21	$\frac{2}{21}$	32			64	44	
400	20	$\frac{2}{20}$						
401	21	$\frac{2}{21}$	56	32	24	76 [1]		
402	21	$\frac{2}{21}$	28			48	44	
403	20	$\frac{2}{20}$	64	24	40	32		24
404	20	$\frac{2}{20}$	72	24	40	48		24
405	20	$\frac{2}{20}$	64			32	24	44
406	20	$\frac{2}{20}$	40			24	24	44
407	20	$\frac{2}{20}$	40			28	24	44
408	20	$\frac{2}{20}$	40			32	24	44
409	20	$\frac{2}{20}$	40	24	32	48		24
410	41	$\frac{4}{41}$						

NOTE. Special gears in this and following tables are 46, 47, 52, 58, 68, 70, 76, 84.

[1] Special gear.

Number of Divisions	Index Circle	No. of Turns of Index	Gear on Worm	No. 1 Hole		Gear on Spindle	Idlers	
				First Gear on Stud	Second Gear on Stud		No. 1 Hole	No. 2 Hole
411	21	$\frac{2}{21}$	28			24	56	
412	20	$\frac{2}{20}$	40			48	24	44
413	21	$\frac{2}{21}$	48			32	44	
414	21	$\frac{2}{21}$	56			32	44	
415	20	$\frac{2}{20}$	32			48	24	44
416	20	$\frac{2}{20}$	40			64	24	44
417	21	$\frac{2}{21}$	56	32	48	24		
418	20	$\frac{2}{20}$	40			72	24	44
419	33	$\frac{3}{33}$	44	28	24	72		
420	21	$\frac{2}{21}$						
421	20	$\frac{2}{20}$	48	56	40	72		24
422	20	$\frac{2}{20}$	40	44	32	64		24
423	21	$\frac{2}{21}$	72	24	56	48		24
424	43	$\frac{4}{43}$	86	24	24	48		
425	21	$\frac{2}{21}$	72	48	56	40		24
426	21	$\frac{2}{21}$	56			32	24	44
427	20	$\frac{2}{20}$	40	48	32	72		24
428	20	$\frac{2}{20}$	40	56	32	64		24
429	21	$\frac{2}{21}$	28			24	24	44
430	43	$\frac{4}{43}$						
431	21	$\frac{2}{21}$	72	44	28	48		24
432	20	$\frac{2}{20}$	40	56	28	64		24
433	20	$\frac{2}{20}$	40	44	24	72		24
434	21	$\frac{2}{21}$	48			64	24	44
435	21	$\frac{2}{21}$	28			40	24	44
436	20	$\frac{2}{20}$	40	48	24	72		24
437	23	$\frac{2}{23}$	32			64	44	
438	21	$\frac{2}{21}$	28			48	24	44
439	43	$\frac{4}{43}$	86	24	24	72		24
440	33	$\frac{8}{33}$						
441	21	$\frac{2}{21}$	32			64	24	44
442	20	$\frac{2}{20}$	40	56	24	72		24
443	20	$\frac{2}{20}$	40	48	24	86		24
444	21	$\frac{2}{21}$	56	48	24	64		24
445	33	$\frac{8}{33}$	64	32	44	40		24
446	33	$\frac{8}{33}$	44			24	24	48
447	21	$\frac{2}{21}$	28			72	24	44
448	20	$\frac{2}{20}$	40	64	24	72		24
449	33	$\frac{8}{33}$	64	32	44	72		24
450	33	$\frac{8}{33}$	44			40	24	32

Number of Divisions	Index Circle	No. of Turns of Index	Gear on Worm	No. 1 Hole		Gear on Spindle	Idlers	
				First Gear on Stud	Second Gear on Stud		No. 1 Hole	No. 2 Hole
451	33	$\frac{3}{33}$	24			24	24	44
452	33	$\frac{3}{33}$	44			48	24	40
453	33	$\frac{3}{33}$	44			52[1]	24	40
454	49	$\frac{4}{49}$	56	64	28	72		
455	49	$\frac{4}{49}$	28	40	32	64		
456	21	$\frac{2}{21}$	56	64	24	72		24
457	33	$\frac{3}{33}$	44			68[1]	24	40
458	33	$\frac{3}{33}$	44			72	24	24
459	27	$\frac{2}{27}$	24	48	24	72		
460	23	$\frac{2}{23}$						
461	33	$\frac{3}{33}$	44	28	24	72		24
462	33	$\frac{3}{33}$	32			64	24	44
463	21	$\frac{2}{21}$	56	64	24	86		24
464	33	$\frac{3}{33}$	44	48	28	56		24
465	33	$\frac{3}{33}$	44	24	24	100		24
466	49	$\frac{4}{49}$	56	48	28	64		
467	33	$\frac{3}{33}$	44	48	32	72		24
468	39	$\frac{3}{39}$	28	48	24	56		
469	49	$\frac{4}{49}$	28			48	44	
470	47	$\frac{4}{47}$						
471	49	$\frac{4}{49}$	56	32	28	76[1]		
472	49	$\frac{4}{49}$	56	32	28	72		
473	33	$\frac{3}{33}$	48	64	32	72		24
474	49	$\frac{4}{49}$	56	32	28	64		
475	49	$\frac{4}{49}$	56	40	28	48		
476	49	$\frac{4}{49}$	56			64	24	
477	27	$\frac{2}{27}$	24	48	24	56		
478	49	$\frac{4}{49}$	56	24	28	64		
479	49	$\frac{4}{49}$	56	32	28	44		
480	49	$\frac{4}{49}$	56	32	28	40		
481	37	$\frac{3}{37}$	24			24	56	
482	33	$\frac{3}{33}$	44	56	24	72		24
483	49	$\frac{4}{49}$	56			32	44	
484	49	$\frac{4}{49}$	56	24	28	32		
485	23	$\frac{2}{23}$	46[1]	24	24	100		24
486	27	$\frac{2}{27}$	32	56	28	64		
487	39	$\frac{3}{39}$	24	72	52[1]	44		
488	33	$\frac{3}{33}$	44	64	24	72		24
489	23	$\frac{2}{23}$	46[1]	58[1]	32	64		24
490	49	$\frac{4}{49}$						

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[1] Special gear.

Number of Divisions	Index Circle	No. of Turns of Index	Gear on Worm	No. 1 Hole		Gear on Spindle	Idlers	
				First Gear on Stud	Second Gear on Stud		No. 1 Hole	No. 2 Hole
491	33	$\frac{8}{33}$	44	68[1]	24	72		24
492	41	$\frac{8}{41}$	28	48	24	56		
493	29	$\frac{2}{29}$	32	64	24	72		
494	39	$\frac{8}{39}$	32			64	44	
495	27	$\frac{2}{27}$	32	40	24	64		
496	49	$\frac{4}{49}$	56	24	28	32		24
497	49	$\frac{4}{49}$	56			32	24	44
498	27	$\frac{2}{27}$	48	56	24	64		
499	49	$\frac{4}{49}$	56	24	28	48		24
500	49	$\frac{4}{49}$	56	32	28	40		24
501	49	$\frac{4}{49}$	56	32	28	44		24
502	49	$\frac{4}{49}$	56	32	28	48		24
503	23	$\frac{2}{23}$	46[1]	64	32	86		24
504	49	$\frac{4}{49}$	56			64	24	24
505	49	$\frac{4}{49}$	56	40	28	48		24
506	49	$\frac{4}{49}$	56	32	28	64		24
507	39	$\frac{8}{39}$	24			24	56	
508	49	$\frac{4}{49}$	56	32	28	72		24
509	49	$\frac{4}{49}$	56	32	28	76[1]		24
510	49	$\frac{4}{49}$	56	40	28	64		24
511	49	$\frac{4}{49}$	28			48	24	44
512	49	$\frac{4}{49}$	56	44	28	64		24
513	27	$\frac{2}{27}$	32			64	44	
514	49	$\frac{4}{49}$	56	48	28	64		24
515	27	$\frac{2}{27}$	72	32	24	100		
516	43	$\frac{8}{43}$	32	56	28	64		
517	49	$\frac{4}{49}$	56	48	28	72		24
518	49	$\frac{4}{49}$	28			64	24	44
519	27	$\frac{2}{27}$	72	56	32	64		
520	39	$\frac{8}{39}$						
521	27	$\frac{2}{27}$	72	76[1]	48	64		
522	29	$\frac{2}{29}$	48	64	24	72		
523	27	$\frac{2}{27}$	72	68[1]	48	64		
524	27	$\frac{2}{27}$	72	32	24	64		
525	27	$\frac{2}{27}$	72	40	32	64		
526	49	$\frac{4}{49}$	56	64	28	72		24
527	31	$\frac{2}{31}$	32	64	24	72		
528	27	$\frac{2}{27}$	72	24	24	64		
529	27	$\frac{2}{27}$	72	44	48	64		
530	15	$\frac{1}{15}$	24	56	32	64		

[1] Special gear.

Number of Divisions	Index Circle	No. of Turns of Index	Gear on Worm	No. 1 Hole		Gear on Spindle	Idlers	
				First Gear on Stud	Second Gear on Stud		No. 1 Hole	No. 2 Hole
531	27	$\frac{2}{27}$	72			48	24	
532	27	$\frac{2}{27}$	72	32	48	64		
533	27	$\frac{2}{27}$	72	32	48	56		
534	27	$\frac{2}{27}$	72			32	44	
535	27	$\frac{2}{27}$	72	32	48	40		
536	39	$\frac{3}{39}$	52[1]			64	24	44
537	27	$\frac{2}{27}$	72	28	56	32		
538	29	$\frac{2}{29}$	58[1]	56	24	72		
539	49	$\frac{4}{49}$	28	48	24	56		24
540	27	$\frac{2}{27}$						
541	39	$\frac{3}{39}$	52[1]	56	32	48		24
542	39	$\frac{3}{39}$	52[1]	44	32	64		24
543	27	$\frac{2}{27}$	72	24	48	32		24
544	15	$\frac{1}{15}$	40	56	24	64		
545	15	$\frac{1}{15}$	32	44	24	64		
546	39	$\frac{3}{39}$	32			64	24	44
547	27	$\frac{2}{27}$	72	32	48	56		24
548	27	$\frac{2}{27}$	72	32	48	64		24
549	27	$\frac{2}{27}$	72			48	24	24
550	15	$\frac{1}{15}$	32	40	24	64		
551	29	$\frac{2}{29}$	32			64	44	
552	27	$\frac{2}{27}$	72	24	24	64		24
553	49	$\frac{4}{49}$	28	48	24	72		24
554	27	$\frac{2}{27}$	72	56	48	64		24
555	15	$\frac{1}{15}$	24			72	44	
556	15	$\frac{1}{15}$	24	44	40	64		
557	15	$\frac{1}{15}$	40	32	24	86		
558	27	$\frac{2}{27}$	48			64	24	44
559	39	$\frac{3}{39}$	24			72	24	44
560	43	$\frac{3}{43}$	86	40	32	64		
561	27	$\frac{2}{27}$	72	56	32	64		24
562	27	$\frac{2}{27}$	72	44	24	64		24
563	29	$\frac{2}{29}$	58[1]			68[1]	44	
564	43	$\frac{3}{43}$	86	24	24	56		
565	15	$\frac{1}{15}$	24			56	44	
566	43	$\frac{3}{43}$	86	24	24	44		
567	15	$\frac{1}{15}$	32	44	40	64		
568	15	$\frac{1}{15}$	40	32	24	64		
569	29	$\frac{2}{29}$	58[1]			44	24	
570	15	$\frac{1}{15}$	32			64	44	

[1] Special gear.

Number of Divisions	Index Circle	No. of Turns of Index	Gear on Worm	No. 1 Hole		Gear on Spindle	Idlers	
				First Gear on Stud	Second Gear Stud		No. 1 Hole	No. 2 Hole
571	43	$\frac{3}{43}$	86	28	64	32		
572	15	$\frac{1}{15}$	40	28	24	64		
573	15	$\frac{1}{15}$	40			72	24	
574	41	$\frac{3}{41}$	32			64	24	44
575	15	$\frac{1}{15}$	24			40	44	
576	15	$\frac{1}{15}$	40			64	24	
577	43	$\frac{3}{43}$	86	32	64	44		24
578	15	$\frac{1}{15}$	48	44	40	64		
579	15	$\frac{1}{15}$	40			56	44	
580	29	$\frac{2}{29}$						
581	15	$\frac{1}{15}$	48	32	40	76[1]		
582	15	$\frac{1}{15}$	40			48	44	
583	27	$\frac{2}{27}$	72	64	24	86		24
584	15	$\frac{1}{15}$	48	32	40	64		
585	15	$\frac{1}{15}$	24			24	56	
586	15	$\frac{1}{15}$	72	48	40	56		
587	29	$\frac{2}{29}$	58[1]			28	24	44
588	15	$\frac{1}{15}$	40			32	44	
589	15	$\frac{1}{15}$	72	44	40	48		
590	15	$\frac{1}{15}$	48			32	44	
591	15	$\frac{1}{15}$	40			24	44	
592	16	$\frac{1}{16}$	24			72	44	
593	15	$\frac{1}{15}$	72	28	40	48		
594	33	$\frac{2}{33}$	32	56	28	64		
595	15	$\frac{1}{15}$	72			24	44	
596	15	$\frac{1}{15}$	72	24	40	32		
597	33	$\frac{2}{33}$	44	56	24	72		
598	16	$\frac{1}{16}$	64	56	24	72		
599	43	$\frac{3}{43}$	86	44	24	84		24
600	15	$\frac{1}{15}$						
601	29	$\frac{2}{29}$	58[1]	56	48	72		24
602	43	$\frac{3}{43}$	32			64	24	44
603	15	$\frac{1}{15}$	72	24	40	24		24
604	16	$\frac{1}{16}$	32			72	24	
605	15	$\frac{1}{15}$	72			24	24	44
606	15	$\frac{1}{15}$	72	24	40	48		24
607	15	$\frac{1}{15}$	72	28	40	48		24
608	16	$\frac{1}{16}$	32			64	44	
609	15	$\frac{1}{15}$	40			24	24	44
610	15	$\frac{1}{15}$	48			32	24	44

[1] Gear Special.

Number of Divisions	Index Circle	No. of Turns of Index	Gear on Worm	No. 1 Hole		Gear on Spindle	No. 2 Hole	
				First Gear on Stud	Second Gear on Stud		No. 1 Hole	No. 2 Hole
611	15	$\frac{1}{15}$	72	44	40	48		24
612	15	$\frac{1}{15}$	40			32	24	44
613	16	$\frac{1}{16}$	64	48	32	72		
614	15	$\frac{1}{15}$	72	48	40	56		24
615	15	$\frac{1}{15}$	24			24	24	44
616	16	$\frac{1}{16}$	32			48	44	
617	33	$\frac{2}{33}$	44	32	24	86		
618	15	$\frac{1}{15}$	40			48	24	44
619	16	$\frac{1}{16}$	48	28	32	72		
620	31	$\frac{2}{31}$						
621	15	$\frac{1}{15}$	40			56	24	44
622	16	$\frac{1}{16}$	64	24	24	72		
623	16	$\frac{1}{16}$	64	24	24	68[1]		
624	16	$\frac{1}{16}$	24			24	56	
625	15	$\frac{1}{15}$	24			40	24	44
626	16	$\frac{1}{16}$	32			28	56	
627	15	$\frac{1}{15}$	40			72	24	44
628	16	$\frac{1}{16}$	32			24	56	
629	16	$\frac{1}{16}$	64			44	24	
630	16	$\frac{1}{16}$	64			40	24	
631	16	$\frac{1}{16}$	64	28	56	72		
632	16	$\frac{1}{16}$	64			32	44	
633	16	$\frac{1}{16}$	64			28	44	
634	16	$\frac{1}{16}$	64			24	44	
635	15	$\frac{1}{15}$	24			56	24	44
636	16	$\frac{1}{16}$	56	28	48	24		
637	49	$\frac{8}{49}$	24			24	56	
638	29	$\frac{2}{29}$	48	64	24	72		24
639	33	$\frac{2}{33}$	44	28	32	64		
640	16	$\frac{1}{16}$						
641	33	$\frac{2}{33}$	44	32	48	76[1]		
642	16	$\frac{1}{16}$	72	24	64	24		24
643	16	$\frac{1}{16}$	64	28	56	24		24
644	49	$\frac{8}{49}$	56			32	44	
645	15	$\frac{1}{15}$	24			72	24	44
646	16	$\frac{1}{16}$	64			24	24	44
647	16	$\frac{1}{16}$	64			28	24	44
648	16	$\frac{1}{16}$	64			32	24	44
649	33	$\frac{2}{33}$	72			48	24	
650	16	$\frac{1}{16}$	64			40	24	44

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[1] Special gear.

Number of Divisions	Index Circle	No. of Turns of Index	Gear on Worm	No. 1 Hole		Gear on Spindle	No. 2 Hole	
				First Gear on Stud	Second Gear on Stud		No. 1 Hole	No. 2 Hole
651	16	$\frac{1}{16}$	64			44	24	24
652	16	$\frac{1}{16}$	32			24	24	44
653	33	$\frac{2}{33}$	72	28	44	48		
654	16	$\frac{1}{16}$	64			56	24	44
655	16	$\frac{1}{16}$	64	40	32	48		24
656	16	$\frac{1}{16}$	24			24	24	44
657	18	$\frac{1}{18}$	32	48	24	56		
658	16	$\frac{1}{16}$	64	24	24	72		24
659	16	$\frac{1}{16}$	64	24	24	76[1]		24
660	33	$\frac{2}{33}$						
661	16	$\frac{1}{16}$	64	56	48	72		24
662	16	$\frac{1}{16}$	64	44	24	48		24
663	17	$\frac{1}{17}$	24			24	56	
664	16	$\frac{1}{16}$	32			48	24	44
665	49	$\frac{3}{49}$	56			40	24	44
666	18	$\frac{1}{18}$	24			72	44	
667	16	$\frac{1}{16}$	64	48	32	72		24
668	16	$\frac{1}{16}$	32			56	24	44
669	33	$\frac{2}{33}$	44			24	24	24
670	33	$\frac{2}{33}$	72	48	44	40		24
671	33	$\frac{2}{33}$	72			48	24	24
672	18	$\frac{1}{18}$	24			64	44	
673	16	$\frac{1}{16}$	48	44	32	72		24
674	33	$\frac{2}{33}$	72	56	44	48		24
675	33	$\frac{2}{33}$	44			40	24	24
676	16	$\frac{1}{16}$	32			72	24	44
677	18	$\frac{1}{18}$	48	32	24	86		
678	18	$\frac{1}{18}$	24			56	44	
679	49	$\frac{3}{49}$	28			44	24	40
680	17	$\frac{1}{17}$						
681	33	$\frac{2}{33}$	44			56	24	24
682	33	$\frac{2}{33}$	48			64	24	24
683	16	$\frac{1}{16}$	32			86	24	44
684	18	$\frac{1}{18}$	32			64	44	
685	18	$\frac{1}{18}$	24	56	48	40		
686	15	$\frac{1}{15}$	40	64	24	86		24
687	18	$\frac{1}{18}$	24			44	48	
688	16	$\frac{1}{16}$	24			72	24	44
689	39	$\frac{2}{39}$	24	48	24	56		
690	18	$\frac{1}{18}$	24			40	56	

[1] Special gear.

Number of Divisions	Index Circle	No. of Turns of Index	Gear on Worm	No. 1 Hole		Gear on Spindle	Idlers	
				First Gear on Stud	Second Gear on Stud		No. 1 Hole	No. 2 Hole
691	18	$\frac{1}{18}$	48	32	24	58[1]		
692	18	$\frac{1}{18}$	72	56	32	64		
693	18	$\frac{1}{18}$	32			48	44	
694	17	$\frac{1}{17}$	68[1]			56	24	44
695	18	$\frac{1}{18}$	72	24	24	100		
696	18	$\frac{1}{18}$	24			32	56	
697	17	$\frac{1}{17}$	24			24	24	44
698	18	$\frac{1}{18}$	72	44	24	48		
699	18	$\frac{1}{18}$	48			56	44	
700	18	$\frac{1}{18}$	72	40	32	64		
701	17	$\frac{1}{17}$	68[1]	48	32	56		24
702	18	$\frac{1}{18}$	24			24	56	
703	19	$\frac{1}{19}$	24			72	44	
704	18	$\frac{1}{18}$	72	24	24	64		
705	18	$\frac{1}{18}$	48			40	44	
706	18	$\frac{1}{18}$	72			56	24	
707	18	$\frac{1}{18}$	72			52[1]	24	
708	18	$\frac{1}{18}$	72			48	24	
709	18	$\frac{1}{18}$	72			44	24	
710	18	$\frac{1}{18}$	72			40	24	
711	18	$\frac{1}{18}$	64			32	44	
712	18	$\frac{1}{18}$	72			32	24	
713	18	$\frac{1}{18}$	72			28	44	
714	18	$\frac{1}{18}$	72			24	44	
715	18	$\frac{1}{18}$	72	32	64	40		
716	18	$\frac{1}{18}$	72	28	56	32		
717	18	$\frac{1}{18}$	72	24	64	32		
718	33	$\frac{2}{33}$	44	58[1]	24	64		24
719	17	$\frac{1}{17}$	68[1]	52[1]	24	72		24
720	18	$\frac{1}{18}$						
721	21	$\frac{1}{21}$	24	64	32	68[1]		
722	19	$\frac{1}{19}$	32			64	44	
723	18	$\frac{1}{18}$	72	24	64	32		24
724	18	$\frac{1}{18}$	72	28	56	32		24
725	18	$\frac{1}{18}$	72	24	48	40		24
726	18	$\frac{1}{18}$	72			24	24	44
727	18	$\frac{1}{18}$	72			28	24	44
728	18	$\frac{1}{18}$	72			32	24	44
729	18	$\frac{1}{18}$	64			32	24	44
730	20	$\frac{1}{20}$	32	48	24	56		

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[1] Special gear.

TABLE FOR INDEXING ANGLES—INDEX PLATES (see explanation on page 453b)

Holes	15	16	17	18	19	20	21	23	27	29	31	33	37	39	41	43	47	49	Holes
1	0.0666	0.0625	0.0588	0.0555	0.0526	0.0500	0.0476	0.0435	0.0370	0.0345	0.0323	0.0303	0.0270	0.0256	0.0244	0.0233	0.0213	0 0204	1
2	0.1333	0.1250	0.1176	0.1111	0.1053	0.1000	0.0952	0.0870	0.0741	0.0690	0.0645	0.0606	0 0541	0.0513	0 0488	0.0465	0.0426	0.0408	2
3	0.2000	0.1875	0.1765	0.1666	0.1579	0.1500	0.1429	0.1304	0.1111	0.1034	0.0968	0.0909	0.0811	0.0769	0.0732	0.0698	0.0638	0 0612	3
4	0.2667	0.2500	0.2353	0.2222	0.2105	0.2000	0.1904	0.1739	0.1481	0.1379	0.1290	0.1212	0.1081	0.1026	0.0976	0.0930	0.0851	0 0816	4
5	0.3333	0.3125	0.2941	0.2777	0.2632	0.2500	0.2381	0.2174	0.1852	0.1724	0.1613	0.1515	0.1351	0.1282	0.1220	0.1163	0.1064	0.1020	5
6	0.4000	0.3750	0.3529	0.3333	0.3158	0.3000	0.2857	0.2609	0.2222	0.2069	0.1935	0.1818	0.1622	0.1538	0.1463	0.1395	0.1277	0.1224	6
7	0.4667	0.4375	0.4118	0.3888	0.3684	0.3500	0.3333	0.3043	0.2593	0.2414	0.2258	0.2121	0.1892	0.1795	0.1707	0.1628	0.1489	0.1429	7
8	0.5333	0.5000	0.4706	0.4444	0.4211	0.4000	0.3810	0.3478	0.2963	0.2759	0.2581	0.2424	0.2162	0.2051	0.1951	0.1860	0.1702	0.1633	8
9	0.6000	0.5625	0.5294	0.5000	0.4737	0.4500	0.4286	0.3913	0.3333	0.3103	0.2903	0.2727	0.2432	0.2308	0.2195	0.2093	0.1915	0.1837	9
10	0.6666	0.6250	0.5882	0.5555	0.5263	0.5000	0.4762	0.4348	0 3703	0.3448	0.3226	0.3030	0.2703	0.2564	0.2439	0.2326	0.2128	0.2040	10
11	0.7333	0.6875	0.6471	0.6111	0.5789	0.5500	0.5238	0.4783	0 4074	0.3793	0.3548	0.3333	0.2973	0.2821	0.2683	0.2558	0.2340	0.2245	11
12	0.8000	0.7500	0.7059	0.6666	0.6316	0.6000	0.5714	0.5217	0.4444	0.4138	0.3871	0.3636	0.3243	0.3077	0.2927	0.2791	0.2553	0.2449	12
13	0.8666	0.8125	0.7647	0.7222	0.6842	0.6500	0.6190	0.5652	0.4815	0.4483	0.4194	0.3939	0.3514	0.3333	0.3171	0.3023	0.2766	0.2653	13
14	0.9333	0.8750	0.8230	0.7777	0.7368	0.7000	0.6666	0.6087	0.5185	0.4827	0 4516	0.4242	0.3784	0.3590	0.3415	0.3256	0.2979	0.2857	14
15		0.9375	0.8824	0.8333	0.7895	0.7500	0.7143	0.6522	0.5555	0.5172	0.4839	0.4545	0.4054	0.3846	0.3659	0.3488	0.3191	0.3061	15
16			0.9412	0.8888	0.8421	0.8000	0.7619	0.6957	0.5924	0.5517	0.5161	0.4848	0.4324	0.4103	0 3902	0.3721	0.3404	0.3265	16
17				0.9444	0.8947	0.8500	0.8095	0.7391	0.6296	0.5862	0.5484	0.5151	0.4596	0.4359	0.4146	0.3954	0.3617	0.3469	17
18					0.9474	0.9000	0.8571	0.7826	0.6666	0.6207	0 5806	0.5454	0.4865	0 4615	0.4390	0.4186	0.3830	0.3673	18
19						0.9500	0.9048	0.8261	0.7037	0.6552	0.6129	0.5757	0 5135	0.4872	0 4634	0.4419	0.4043	0.3878	19
20							0.9524	0.8696	0.7407	0.6897	0.6452	0.6060	0 5405	0.5128	0.4878	0.4651	0.4255	0.4082	20
21								0.9130	0.7777	0.7241	0.6774	0.6363	0.5676	0.5385	0.5122	0.4884	0.4468	0.4286	21
22								0.9565	0.8148	0.7586	0.7097	0 6666	0 5946	0.5641	0.5366	0 5116	0.4681	0.4490	22
									0 8519	0.7931	0.7419	0.6969	0 6216	0.5897	0.5610	0.5349	0.4894	0.4694	23
									0 8888	0.8276	0.7742	0.7272	0 6486	0 6154	0 5854	0.5581	0.5106	0.4898	24

TABLE FOR INDEXING ANGLES

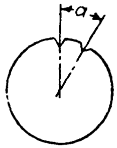
The table saves many calculations when obtaining proper index for angles, either in degrees, minutes or seconds, or all three collectively. An example will readily show its application.

The angle to be indexed is one of 31 deg., 17 min., 11 sec. Reducing the angle to seconds = 112,631. One turn of the crank = 9 deg., which reduced to seconds = 32,400.

$$\frac{112,631}{32,400} = 3.4762 \textit{ turns}$$

We find in the table 0.4762 = $\frac{10}{21}$; thus, three turns and 10 holes on the 21 circle give correct results to four decimal places.

Index Plates	27	29	31	33	37	39	41	43	47	49	Holes
	0.9259	0.8621	0.8065	0.7575	0.6757	0.6410	0.6098	0.5814	0.5319	0.5102	25
	0.9630	0.8966	0.8387	0.7878	0.7027	0.6666	0.6341	0.6047	0.5532	0.5306	26
		0.9310	0.8710	0.8181	0.7297	0.6923	0.6585	0.6279	0.5745	0.5510	27
		0.9655	0.9032	0.8484	0.7568	0.7179	0.6829	0.6512	0.5957	0.5714	28
			0.9355	0.8787	0.7838	0.7436	0.7073	0.6744	0.6170	0.5918	29
			0.9677	0.9090	0.8108	0.7692	0.7317	0.6977	0.6383	0.6122	30
				0.9393	0.8378	0.7949	0.7561	0.7209	0.6596	0.6326	31
				0.9696	0.8647	0.8205	0.7805	0.7442	0.6809	0.6531	32
					0.8919	0.8462	0.8049	0.7674	0.7021	0.6735	33
					0.9189	0.8718	0.8293	0.7907	0.7234	0.6939	34
					0.9459	0.8974	0.8537	0.8140	0.7447	0.7143	35
					0.9730	0.9231	0.8780	0.8372	0.7760	0.7347	36
						0.9487	0.9024	0.8605	0.7872	0.7551	37
						0.9743	0.9268	0.8837	0.8085	0.7755	38
							0.9512	0.9070	0.8298	0.7959	39
							0.9756	0.9302	0.8511	0.8163	40
								0.9535	0.8723	0.8367	41
								0.9768	0.8936	0.8571	42
									0.9149	0.8775	43
									0.9362	0.8980	44
									0.9574	0.9184	45
									0.9787	0.9388	46
										0.9592	47
										0.9796	48



WIDE-RANGE DIVIDER

A wide-range divider is made by the Cincinnati Milling Machine Company for use with their dividing heads for rapidly selecting divisions from 2 to 400,000 and any angle in degrees, minutes, and seconds. This is built into the dividing head, as in Fig. 26. It has a large and a small index plate, each with a sector and crank. The small crank operates a 100:1 ratio while the other is the conventional 40:1 ratio. By using the large crank, the usual divisions are obtained. For other divisions, the wide-range divider is used. Figure 26 shows the large reversible index plate with eleven circles of holes at *A* with sector for spacing; swivel crank *B* (which can be set from position shown to any circle to dotted position); small index plate *C* and sector *G* for spacing; crank *D* for small plate, which has two circles of holes, namely, 100 and 54.

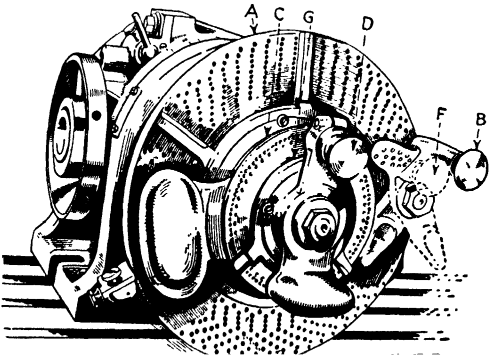


FIG. 26.—Cincinnati Wide-Range Dividing Head.

How to Use the Wide Range Divider.—Any whole number of divisions, up to and including 60, and hundreds of others, can be obtained with the large plate only, and many of the settings may be read directly from the table, pages 453*a* and 453*b*. If the number of divisions required is not listed in the table, calculate the setting in the following manner:

Setup:

1. Divide 400,000 by the number of divisions desired, for example, 67. The result gives you a whole number quotient and a fraction, 5970$\frac{10}{67}$.
2. Set the sector on large index plate *A* for 59 spaces on the 100-hole circle, 59 being the first two whole numbers of the quotient obtained.
3. Set the sector on the small index plate *C* for 70 spaces on the 100-hole circle, 70 being the last two whole numbers of the quotient obtained.

Should the quotient be a five-digit number, the first number represents the number of full turns of crank *B*. (No five-digit quotient appears when making divisions higher than 40, and furthermore, calculations are unnecessary for any number less than 61.)

Operation:

4. Index crank *B* an amount equal to the sector setting, namely, 59 spaces (see Fig. 26).

5. Then index crank *D* an amount equal to the sector setting, namely, 70 spaces. (Both cranks are moved in the same direction.)

6. Compensate for fraction $\frac{10}{67}$ by adding one space to the index movement of the small crank *D* at intervals equal to the nearest whole number obtained by dividing 1 by $\frac{10}{67}$. The result of this division is 7. Therefore, every seventh division, index 71 spaces on the small plate *C* instead of 70. In this way you pick up the fractional remainder, and the maximum error is only equal to 0.0000942 inch on a 12-inch diameter circle (the movement of one space in the 100-hole circle on the small plate).

Angular Spaced Divisions.—If the divisions are spaced in degrees, minutes, and seconds, the procedure in calculating the setting is very similar to that outlined above, except that for sake of convenience, use the 54-hole circle on both plates. Complete tables are listed in Tables 9*a* and 9*b*.

Using crank *B* on the large plate (Fig. 26):

1. One complete turn is equivalent to 9 degrees.
2. Six spaces in the 54-hole circle equals 1 degree.
3. One space in the 54-hole circle equals 10 minutes.

Using crank *D* on the small plate:

1. One complete turn of crank *D* equals 5 minutes and 24 seconds.
2. Ten spaces in 54-hole circle equals 1 minute.
3. One space in 54-hole circle equals 6 seconds.

EXAMPLE.—Indexing an angle of 3 degrees, 20 minutes, 12 seconds.

Setup:

1. Consult the Degree table on page 454*b*, and set the sector on index plate *A* (Fig. 26) for 18 spaces on the 54-hole circle.

2. Consult the Fractions of a Degree table on page 454*d*, and set sector *G* on plate *C* for 40 spaces on the 54-hole circle.

Operation:

1. Index large crank *B* (Fig. 26) an amount equal to the sector setting, namely, 18 spaces.

2. Index small crank *D* three turns (see table) plus the sector setting, namely, 40 spaces. (Both cranks are moved in the same direction.)

The index pin in the crank for the small plate is eccentric to provide a method of adjusting the pin from the 100-hole to the 54-hole circle, and vice versa.

TABLE 10a.—ANGULAR DIVISIONS IN DEGREES
Obtainable with Standard Dividing Head and Wide-Range Divider
(Use 54-Hole Circle on Large Plate)

Degrees	Turns of Crank *B*	Spaces Crank *B*	Degrees	Turns of Crank *B*	Spaces Crank *B*	Degrees	Turns of Crank *B*	Spaces Crank *B*	Degrees	Turns of Crank *B*	Spaces Crank *B*	Degrees	Turns of Crank *B*	Spaces Crank *B*	Degrees	Turns of Crank *B*	Spaces Crank *B*	Degrees	Turns of Crank *B*	Spaces Crank *B*	Degrees	Turns of Crank *B*	Spaces Crank *B*	Degrees	Turns of Crank *B*	Spaces Crank *B*
1	....	6	41	4	30	81	9	....	121	13	24	161	17	48	201	22	18	241	26	42	281	31	12	321	35	36
2	....	12	42	4	36	82	9	6	122	13	30	162	18	..	202	22	24	242	26	48	282	31	18	322	35	42
3	....	18	43	4	42	83	9	12	123	13	36	163	18	6	203	22	30	243	27	....	283	31	24	323	35	48
4	....	24	44	4	48	84	9	18	124	13	42	164	18	12	204	22	36	244	27	6	284	31	30	324	36	
5	....	30	45	5	....	85	9	24	125	13	48	165	18	18	205	22	42	245	27	12	285	31	36	325	36	6
6	....	36	46	5	6	86	9	30	126	14	....	166	18	24	206	22	48	246	27	18	286	31	42	326	36	12
7	....	42	47	5	12	87	9	36	127	14	6	167	18	30	207	23	.	247	27	24	287	31	48	327	36	18
8	....	48	48	5	18	88	9	42	128	14	12	168	18	36	208	23	6	248	27	30	288	32	....	328	36	24
9	1	....	49	5	24	89	9	48	129	14	18	169	18	42	209	23	12	249	27	36	289	32	6	329	36	30
10	1	6	50	5	30	90	10	....	130	14	24	170	18	48	210	23	18	250	27	42	290	32	12	330	36	36
11	1	12	51	5	36	91	10	6	131	14	30	171	19	....	211	23	24	251	27	48	291	32	18	331	36	42
12	1	18	52	5	42	92	10	12	132	14	36	172	19	6	212	23	30	252	28	...	292	32	24	332	36	48
13	1	24	53	5	48	93	10	18	133	14	42	173	19	12	213	23	36	253	28	6	293	32	30	333	37	
14	1	30	54	6	....	94	10	24	134	14	48	174	19	18	214	23	42	254	28	12	294	32	36	334	37	6
15	1	36	55	6	6	95	10	30	135	15	..	175	19	24	215	23	48	255	28	18	295	32	42	335	37	12
16	1	42	56	6	12	96	10	36	136	15	6	176	19	30	216	24	.	256	28	24	296	32	48	336	37	18
17	1	48	57	6	18	97	10	42	137	15	12	177	19	36	217	24	6	257	28	30	297	33	....	337	37	24
18	2	....	58	6	24	98	10	48	138	15	18	178	19	24	218	24	12	258	28	36	298	33	6	338	37	30
19	2	6	59	6	30	99	11	...	139	15	24	179	19	48	219	24	18	259	28	42	299	33	12	339	37	36
20	2	12	60	6	36	100	11	6	140	15	30	180	20	....	220	24	24	260	28	48	300	33	18	340	37	42

TABLE 10a.—ANGULAR DIVISIONS IN DEGREES.—*Continued*

Degrees	Turns of Crank *B*	Spaces Crank *B*	Degrees	Turns of Crank *B*	Spaces Crank *B*	Degrees	Turns of Crank *B*	Spaces Crank *B*	Degrees	Turns of Crank *B*	Spaces Crank *B*	Degrees	Turns of Crank *B*	Spaces Crank *B*	Degrees	Turns of Crank *B*	Spaces Crank *B*	Degrees	Turns of Crank *B*	Spaces Crank *B*	Degrees	Turns of Crank *B*	Spaces Crank *B*	Degrees	Turns of Crank *B*	Spaces Crank *B*
21	2	18	61	6	42	101	11	12	141	15	36	181	20	6	221	24	30	261	29	....	301	33	24	341	37	48
22	2	24	62	6	48	102	11	18	142	15	42	182	20	12	222	24	36	262	29	6	302	33	30	342	38	
23	2	30	63	7	....	103	11	24	143	15	48	183	20	18	223	24	42	263	29	12	303	33	36	343	38	6
24	2	36	64	7	6	104	11	30	144	16	....	184	20	24	224	24	48	264	29	18	304	33	42	344	38	12
25	2	42	65	7	12	105	11	36	145	16	6	185	20	30	225	25	....	265	29	24	305	33	48	345	38	18
26	2	48	66	7	18	106	11	42	146	16	12	186	20	36	226	25	6	266	29	30	306	34	....	346	38	24
27	3	....	67	7	24	107	11	48	147	16	18	187	20	42	227	25	12	267	29	36	307	34	6	347	38	30
28	3	6	68	7	30	108	12	....	148	16	24	188	20	48	228	25	18	268	29	42	308	34	12	348	38	36
29	3	12	69	7	36	109	12	6	149	16	30	189	21		229	25	24	269	29	48	309	34	18	349	38	42
30	3	18	70	7	42	110	12	12	150	16	36	190	21	6	230	25	30	270	30	....	310	34	24	350	38	48
31	3	24	71	7	48	111	12	18	151	16	42	191	21	12	231	25	36	271	30	6	311	34	30	351	39	
32	3	30	72	8		112	12	24	152	16	48	192	21	18	232	25	42	272	30	12	312	34	36	352	39	6
33	3	36	73	8	6	113	12	30	153	17	....	193	21	24	233	25	48	273	30	18	313	34	42	353	39	12
34	3	42	74	8	12	114	12	36	154	17	6	194	21	30	234	26	....	274	30	24	314	34	48	354	39	18
35	3	48	75	8	18	115	12	42	155	17	12	195	21	36	235	26	6	275	30	30	315	35	....	355	39	24
36	4	....	76	8	24	116	12	48	156	17	18	196	21	42	236	26	12	276	30	36	316	35	6	356	39	30
37	4	6	77	8	30	117	13	....	157	17	24	197	21	48	237	26	18	277	30	42	317	35	12	357	39	36
38	4	12	78	8	36	118	13	6	158	17	30	198	22	....	238	26	24	278	30	48	318	35	18	358	39	42
39	4	18	79	8	42	119	13	12	159	17	36	199	22	6	239	26	30	279	31	....	319	35	24	359	39	48
40	4	24	80	8	48	120	13	18	160	17	42	200	22	12	240	26	36	280	31	6	320	35	30	360	40	

TABLE 10b.—ANGULAR DIVISIONS IN FRACTIONS OF A DEGREE Obtainable with Wide-Range Divider (Use 54-Hole Circle on Small Plate)

Minutes	Seconds	Turns of Crank *D*	Spaces Crank *D*	Minutes	Seconds	Turns of Crank *D*	Spaces Crank *D*	Minutes	Seconds	Turns of Crank *D*	Spaces Crank *D*	Minutes	Seconds	Turns of Crank *D*	Spaces Crank *D*	Minutes	Seconds	Turns of Crank *D*	Spaces Crank *D*	Minutes	Seconds	Turns of Crank *D*	Spaces Crank *D*	Minutes	Seconds	Turns of Crank *D*	Spaces Crank *D*	Minutes	Seconds	Turns of Crank *D*	Spaces Crank *D*
0	6	...	1	8	...	1	26	16	...	2	52	24	...	4	24	32	..	5	50	40	...	7	22	48	...	8	48	56	...	10	20
0	12	....	2	8	12	1	28	16	12	3	....	24	12	4	26	32	12	5	52	40	12	7	24	48	12	8	50	56	12	10	22
0	24	....	4	8	24	1	30	16	24	3	2	24	24	4	28	32	24	6	.	40	24	7	26	48	24	8	52	56	24	10	24
0	36	..	6	8	36	1	32	16	36	3	4	24	36	4	30	32	36	6	2	40	36	7	28	48	36	9	....	56	36	10	26
0	48	....	8	8	48	1	34	16	48	3	6	24	48	4	32	32	48	6	4	40	48	7	30	48	48	9	2	56	48	10	28
1	...	...	10	9	...	1	36	17	...	3	8	25	...	4	34	33	...	6	6	41	...	7	32	49	...	9	4	57	...	10	30
1	12	...	12	9	12	1	38	17	12	3	10	25	12	4	36	33	12	6	8	41	12	7	34	49	12	9	6	57	12	10	32
1	24	...	14	9	24	1	40	17	24	3	12	25	24	4	38	33	24	6	10	41	24	7	36	49	24	9	8	57	24	10	34
1	36	...	16	9	36	1	42	17	36	3	14	25	36	4	40	33	36	6	12	41	36	7	38	49	36	9	10	57	36	10	36
1	48	....	18	9	48	1	44	17	48	3	16	25	48	4	42	33	48	6	14	41	48	7	40	49	48	9	12	57	48	10	38
2	...	....	20	10	...	1	46	18	...	3	18	26	..	4	44	34	..	6	16	42	...	7	42	50	...	9	14	58	...	10	40
2	12	..	22	10	12	1	48	18	12	3	20	26	12	4	46	34	12	6	18	42	12	7	44	50	12	9	16	58	12	10	42
2	24	...	24	10	24	1	50	18	24	3	22	26	24	4	48	34	24	6	20	42	24	7	46	50	24	9	18	58	24	10	44
2	36	..	26	10	36	1	52	18	36	3	24	26	36	4	50	34	36	6	22	42	36	7	48	50	36	9	20	58	36	10	46
2	48	....	28	10	48	2	....	18	48	3	26	26	48	4	52	34	48	6	24	42	48	7	50	50	48	9	22	58	48	10	48
3	...	....	30	11	...	2	2	19	...	3	28	27	.	5	....	35	...	6	26	43		7	52	51	..	9	24	59	...	10	50
3	12	....	32	11	12	2	4	19	12	3	30	27	12	5	2	35	12	6	28	43	12	8	.	51	12	9	26	59	12	10	52
3	24	....	34	11	24	2	6	19	24	3	32	27	24	5	4	35	24	6	30	43	24	8	2	51	24	9	28	59	24	11	
3	36	...	36	11	36	2	8	19	36	3	34	27	36	5	6	35	36	6	32	43	36	8	4	51	36	9	30	59	36	11	2
3	48	...	38	11	48	2	10	19	48	3	36	27	48	5	8	35	48	6	34	43	48	8	6	51	48	9	32	59	48	11	4

TABLE 10*b*.—ANGULAR DIVISIONS IN FRACTIONS OF A DEGREE.—*Continued*

Minutes	Seconds	Turns of Crank *D*	Spaces Crank *D*	Minutes	Seconds	Turns of Crank *D*	Spaces Crank *D*	Minutes	Seconds	Turns of Crank *D*	Spaces Crank *D*	Minutes	Seconds	Turns of Crank *D*	Spaces Crank *D*	Minutes	Seconds	Turns of Crank *D*	Spaces Crank *D*	Minutes	Seconds	Turns of Crank *D*	Spaces Crank *D*	Minutes	Seconds	Turns of Crank *D*	Spaces Crank *D*	Minutes	Seconds	Turns of Crank *D*	Spaces Crank *D*
4	..	..	40	12	.	2	12	20	..	3	38	28	.	5	10	36	..	6	36	44	.	8	8	52	.	9	34				
4	12	..	42	12	12	2	14	20	12	3	40	28	12	5	12	36	12	6	38	44	12	8	10	52	12	9	36				
4	24	..	44	12	24	2	16	20	24	3	42	28	24	5	14	36	24	6	40	44	24	8	12	52	24	9	38				
4	36	..	46	12	36	2	18	20	36	3	44	28	36	5	16	36	36	6	42	44	36	8	14	52	36	9	40				
4	48	..	48	12	48	2	20	20	48	3	46	28	48	5	18	36	48	6	44	44	48	8	16	52	48	9	42				
5	..	..	50	13	.	2	22	21		3	48	29	.	5	20	37		6	46	45		8	18	53		9	44				
5	12	.	52	13	12	2	24	21	12	3	50	29	12	5	22	37	12	6	48	45	12	8	20	53	12	9	46				
5	24	1	.	13	24	2	26	21	24	3	52	29	24	5	24	37	24	6	50	45	24	8	22	53	24	9	48				
5	36	1	2	13	36	2	28	21	36	4	.	29	36	5	26	37	36	6	52	45	36	8	24	53	36	9	50				
5	48	1	4	13	48	2	30	21	48	4	2	29	48	5	28	37	48	7	.	45	48	8	26	53	49	9	52				
6	..	1	6	14	..	2	32	22	..	4	4	30	.	5	30	38	.	7	2	46	..	8	28	54		10					
6	12	1	8	14	12	2	34	22	12	4	6	30	12	5	32	38	12	7	4	46	12	8	30	54	12	10	2				
6	24	1	10	14	24	2	36	22	24	4	8	30	24	5	34	38	24	7	6	46	24	8	32	54	24	10	4				
6	36	1	12	14	36	2	38	22	36	4	10	30	36	5	36	38	36	7	8	46	36	8	34	54	36	10	6				
6	48	1	14	14	48	2	40	22	48	4	12	30	48	5	38	48	48	7	10	46	48	8	36	54	48	10	8				
7	..	1	16	15	..	2	42	23	..	4	14	31		5	40	39		7	12	47	.	8	38	55		10	10				
7	12	1	18	15	12	2	44	23	12	4	16	31	12	5	42	39	12	7	14	47	12	8	40	55	12	10	12				
7	24	1	20	15	24	2	46	23	24	4	18	31	24	5	44	39	24	7	16	47	24	8	42	55	24	10	14				
7	36	1	22	15	36	2	48	23	36	4	20	31	36	5	46	39	36	7	18	47	36	8	44	55	36	10	16				
7	48	1	24	15	48	2	50	23	48	4	22	31	48	5	48	39	48	7	20	47	48	8	46	55	48	10	18				

NOTE.—When indexing degrees and fractions of a degree, cranks *B* and *D* in above tables are both moved in the same direction.

THE USE OF DIVIDING HEADS

Every milling-machine operator, especially those engaged in tool room work, should familiarize himself with the details and possible uses of both the Cincinnati Wide Range Divider and the two dividing heads made by the Kearney & Trecker Corporation. These dividing heads and their uses are described in considerable detail because of their importance where special divisions, or leads, are necessary to secure the desired results in mechanisms of various kinds.

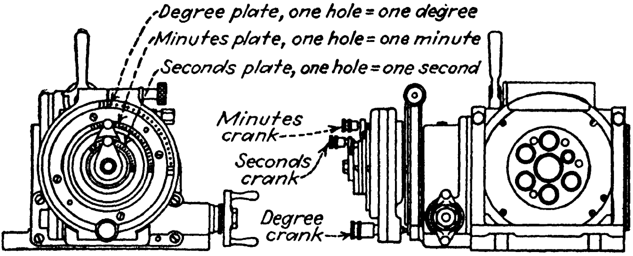

Degree plate, one hole = one degree
Minutes plate, one hole = one minute
Seconds plate, one hole = one second
Minutes crank
Seconds crank
Degree crank

FIG. 27.—Kearney and Trecker Dividing Head.

It should be remembered that the makers of these dividing heads are ready at all times to assist users of the dividing heads in solving special problems which may arise from time to time.

It will be noted on page 455 that the Kearney & Trecker Corporation keeps a master reference book which contains 40,000 leads and that this information is available to all users of their dividing heads at all times.

The brief descriptions and instructions given here will, if carefully studied, be sufficient to enable the milling-machine operator to handle almost any lead problem that may come up in the average shop.

OTHER DIVIDING HEADS

Kearney and Trecker supply either the conventional 40/1 ratio or a special hypoid head with a 5/1 ratio which gives 40,000 different leads from 0.0219 to 2.918.4 inches. All 40,000 leads are kept in a master book at the plant for reference but the instruction book contains 2,258 leads in an approximately geometric progression. It is also furnished for metric screws and gives change gears for thread milling. The hypoid head is shown in Figs. 27 and 28.

Kearney and Trecker also make an astronomical attachment for their dividing head by which the circle is divided into 1,296,000 parts, or into seconds of arc. One second is equal to 0.000024 inch on the periphery of a 10-inch diameter circle, which is the maximum theoretical inaccuracy possible. In practice, however, it is not possible to obtain anywhere near this accuracy, but the heads are guaranteed to within one minute to arc. This attachment can be used with the dividing-head spindle set anywhere between 5 degrees below horizontal to 5 degrees beyond the vertical. It can also be used for milling helices. The formula and its application fllow:

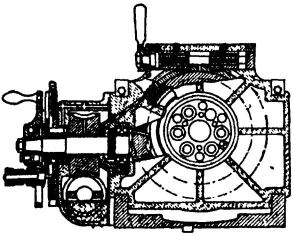


FIG. 28.—Kearney and Trecker Hypoid Dividing Head.

INDEXING WITH THE ASTRONOMICAL DIVIDING ATTACHMENT

Formula.—

$$\frac{1,296,000}{N} = S + R \qquad \text{or} \qquad (S + 1) - (N - R)^*.$$

$$\frac{S}{60} = M + S'.$$

---

* When R is more than $\frac{1}{2}N$ it is preferable to add one one second to S, the Remainder than becoming negative and numerically equal to $N - R$.

$$\frac{M}{60} = D + M'.$$

D = number of holes on degree plate taken at each indexing.
M' = number of holes on minutes plate taken at each indexing.
S' = number of holes on seconds plate taken at each indexing.
R = remainder or total compensation in seconds.
N = number of divisions or indexings required.
S = total seconds in each division.
M = total minutes in each division.

EXAMPLE: 119 DIVISIONS.—

$$\frac{1{,}296{,}000}{119} = 10{,}890S + 90R \quad \text{or} \quad 10{,}891S - 29R.$$

$$\frac{10{,}891}{60} = 181M + 31S'.$$

$$\frac{181}{60} = 3D + 1M'.$$

The setting for 119 divisions is: 3 degrees 1 minute 31 seconds, −29 compensation.

The compensation is most accurately accomplished in the following manner: At the first indexing, $R = -\frac{29}{119}$; at the second, $R = -\frac{29}{119} + (-\frac{29}{119})$ or $-\frac{58}{119}$; at the third, $R = \frac{87}{119}$; at the fourth, $R = -\frac{116}{119}$; at the fifth, $R = -\frac{145}{119}$. Here R is greater than −1, so one hole is dropped on the seconds plate and R becomes $-\frac{145}{119} - (+\frac{119}{119})$ or $-\frac{26}{119}$. Normal indexing is resumed, and at the sixth division $R = -\frac{26}{119} + (-\frac{29}{119})$ or $-\frac{55}{119}$; at the seventh $R = \frac{84}{119}$; at the eighth, $R = \frac{113}{119}$; at the ninth, $R = \frac{142}{119}$. Here again R is greater than −1, so one hole is dropped as at the fifth division.

This procedure is carried on through the 119 divisions dropping holes at the fifth, ninth, thirteenth, seventeenth, twenty-first, twenty-fifth, etc., and R at the 119th division = $-\frac{116}{119}$; this automatically is a check. Compensating in this manner results in the most accurate setting for each division or indexing.

METAL-CUTTING SAWS

Teeth for metal-cutting saws are made in different ways as shown in Fig. 29. Beveling circular saw teeth and offsetting band- and hack-saw teeth reduces friction. The feed that can be used depends on the hardness of the metal and the size of the piece. Hard, close-grained material requires more power and dulls saws sooner than soft materials. Soft or stringy stock requires more clearance and hooked teeth. Saws should be kept sharp and should have no high teeth as these dull quickly and the other teeth do little work. Data from such well-known sawmakers as Atkins, Disston, and Simonds as shown in Tables 11 and 12.

TABLE 100.—CUTTING RACKS ON CINCINNATI MILLING MACHINES

(Using the Table Feed Screw for Making Division)

Pitch 2		Pitch 2¼		Pitch 2½		Pitch 2¾		Pitch 3		Pitch 3½		Pitch 4		Pitch 5		Pitch 6		Pitch 7		Pitch 8		Pitch 9	
Revolutions	Thousandths	Revolutions	Thousandths	Revolutions	Thousandths	Revolutions	Thousandths	Revolutions	Thousandths	Revolutions	Thousandths	Revolutions	Thousandths	Revolutions	Thousandths	Revolutions	Thousandths	Revolutions	Thousandths	Revolutions	Thousandths	Revolutions	Thousandths
6	71	5	146	5	7	4	142	4	47	3	148	3	35	2	128	2	24	1	199	1	143	1	99
6	142	5	42	5	14	4	34	4	94	3	46	3	70	2	6	2	48	1	148	1	36	1	198
6	213	5	188	5	21	4	176	4	141	3	194	3	105	2	134	2	72	1	97	1	179	1	47
6	34	5	84	5	28	4	68	4	188	3	92	3	140	2	12	2	96	1	46	1	72	1	146
6	105	5	230	5	35	4	210	4	235	3	240	3	175	2	140	2	120	1	245	1	215	1	245
6	176	5	126	5	42	4	102	4	32	3	138	3	210	2	18	2	144	1	194	1	108	1	94
6	247	5	22	5	49	4	244	4	79	3	36	3	245	2	146	2	168	1	143	1	1	1	193
6	68	5	168	5	56	4	136	4	126	3	184	3	30	2	24	2	192	1	92	1	144	1	42
6	139	5	64	5	63	4	28	4	173	3	82	3	65	2	152	2	216	1	41	1	37	1	141
6	210	5	210	5	70	4	170	4	220	3	230	3	100	2	30	2	240	1	240	1	180	1	240

DIRECTIONS.—For example: To cut a 9-pitch rack, adjust the work to the cutter and set the micrometer dial of the lead screw to zero.

For the next tooth turn the lead screw crank through one complete revolution plus an additional amount until the micrometer dial reads 99 thousandths. For the following tooth turn the lead screw crank through one revolution and continue until the micrometer reads 198 thousandths, and so on until you reach the last number in above table; then without moving the lead screw set the micrometer dial to zero and commence over again, continuing as before.

To cut a 4-pitch rack the first spacing is 3 revolutions, 35 thousandths; the second 3 revolutions, and pass on to 70 thousandths and so on.

TABLE 10c.—CUTTING RACKS ON CINCINNATI MILLING MACHINES—*Continued*

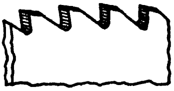
(Using the Table Feed Screw for Making Divisions)

Pitch 10		Pitch 11		Pitch 12		Pitch 14	Pitch 16	Pitch 18	Pitch 20	Pitch 22	Pitch 24	Pitch 26	Pitch 28	Pitch 30	Pitch 32	Pitch 36	Pitch 40	Pitch 48
Revolutions	Thousandths	Revolutions	Thousandths	Revolutions	Thousandths	Thousandths	Thousandths	Thousandths	Thousandths	Thousandths	Thousandths	Thousandths	Thousandths	Thousandths	Thousandths	Thousandths	Thousandths	Thousandths
1	64	1	36	1	12	224	196	175	157	143	131	121	112	105	98	87	79	65
1	128	1	72	1	24	198	142	100	64	36	12	242	224	210	196	174	159	130
1	192	1	108	1	36	172	88	25	221	179	143	113	86	65	44	11	237	195
1	6	1	144	1	48	146	34	200	128	72	24	234	198	170	142	98	66	10
1	70	1	180	1	60	120	230	125	35	215	155	105	60	25	240	185	145	75
1	134	1	216	1	72	94	176	50	192	108	36	226	172	130	88	22	224	140
1	198	1	2	1	84	68	122	225	99	1	167	97	34	235	186	109	53	205
1	12	1	38	1	96	42	68	150	6	144	48	218	146	90	34	196	132	20
1	76	1	74	1	108	16	14	75	163	37	179	89	8	195	132	33	211	85
1	140	1	110	1	120	240	210	250	70	180	60	210	120	50	230	120	40	150

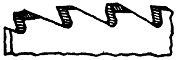
DIRECTIONS.—For example: To cut a 32-pitch rack adjust the work to the cutter and set the micrometer dial of the lead screw to zero.

For the next tooth turn the lead screw crank until the micrometer reads 98 thousandths; for the following tooth continue to turn until the reading is 196 thousandths, for the next, 44 thousandths and so on until you reach the last number in above table; then without moving the lead screw set the micrometer to zero, and commence over again, continuing as before.

For a pitch requiring one or more than one revolution of the screw, follow instructions given on preceding page.



Regular



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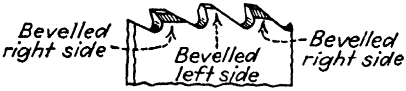
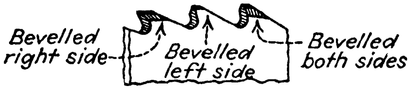


Alternate Side Bevel



Simonds Tooth

FIG. 29.—Metal Saw Teeth

TABLE 11.—NUMBER OF TEETH IN SAWS RECOMMENDED FOR VARIOUS MATERIALS (ATKINS)

These Materials Are General	Thin Small Shapes Tubing Pipe	Medium Sections, Thin Shapes Pipe Tubing	Large Sections, Thin Shapes Tubing Pipe	Small Sections, Thick Wall Pipe Tubing	Thick Wall Pipe	Small Sections, Hard Material	Medium Sections, Hard Material	Large Sections, Hard Material, Structural	Extra Large Sections, Hard Material, Small Sections, Soft Material	Medium Sections, Soft Materials	Large Sections, Soft Materials	Extra Large Sections, Soft Material
Diameter Inches	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
9	224	150	112	90	76	64	56					
10	250	168	124	100	84	72	62					
11	276	184	138	110	92	78	70					
12	....	200	150	120	100	86	76	68				
13	....	....	162	130	108	94	82	72	66			
14	....	....	174	140	116	100	88	78	70	58		
15	....	....	....	150	124	108	94	84	76	62	54	
16	....	....	....	160	134	114	100	90	80	68	58	
18	....	....	....	....	150	130	112	100	90	76	64	
20	....	....	....	....	168	144	124	112	100	84	72	
22	....	....	....	....	184	158	138	122	110	92	80	
24	....	....	....	....	200	172	150	134	120	100	86	76
26	....	....	....	....	218	186	162	144	130	108	94	82
28	....	....	....	....	234	200	176	156	140	118	100	88
30	....	....	....	....	250	214	188	168	150	124	108	94
32	....	....	....	....	268	230	200	178	160	134	112	100
34	....	....	....	....	....	244	212	190	170	142	122	106
36	....	....	....	....	....	258	226	200	180	150	130	114

TABLE 12.—CUTTING SPEEDS FOR COLD SAW CUTTING-OFF MACHINES

Diameter of Stock	Diameter of Saw	Machinery and Soft Steel					Tool Steel					High-speed Tool Steel				
		Number of Teeth in Saw	Cutting Speed of Saw, Ft. per Min.	Feed of Saw Inches per Min.	Revolutions of Saw per Min.	Approx. Min. to Cut Off One Piece	Number of Teeth in Saw	Cutting Speed of Saw, Ft. per Min.	Feed of Saw, Inches per Min.	Revolutions of Saw per Min.	Approx. Min. to Cut Off One Piece	Number of Teeth in Saw	Cutting Speed of Saw, Ft. per Min.	Feed of Saw, Inches per Min.	Revolutions of Saw, per Min.	Approx. Min. to Cut Off One Piece
2	16	76	50	0.88	11.93	2¼	108	70	0.666	16.71	3	108	50	0.250	11.93	8
2½	16	76	50	0.833	11.93	3	108	70	0.555	16.71	4½	108	50	0.250	11.93	10
3	16	76	50	0.750	11.93	4	108	70	0.500	16.71	6	108	50	0.250	11.93	12
3½	16	76	50	0.70	11.93	5	108	70	0.466	16.71	7½	108	50	0.225	11.93	15½
4	18	76	50	0.66	10.61	6	108	70	0.444	14.85	9	108	50	0.210	10.61	19
4½	18	76	50	0.642	10.61	7	108	70	0.409	14.85	11	108	50	0.195	10.61	23
5	18	76	50	0.588	10.61	8½	108	70	0.384	14.85	13	108	50	0.178	10.61	28
5½	18	76	50	0.55	10.61	10	108	70	0.366	14.85	15	108	50	0.166	10.61	33
6	22	86	50	0.50	8.68	12	120	70	0.333	12.15	18	120	50	0.153	8.68	39
6½	22	86	50	0.464	8.68	14	120	70	0.309	12.15	21	120	50	0.138	8.68	47
7	24	86	50	0.411	7.95	17	120	70	0.280	11.14	25	120	50	0.126	7.95	55
7½	24	86	50	0.357	7.95	21	120	70	0.250	11.14	30	120	50	0.116	7.95	64
8	24	86	50	0.307	7.95	26	120	70	0.228	11.14	35	120	50	0.108	7.95	74

The experience of the Atkins company has led to adoption of the saw tooth shown in Fig. 30. This allows a slower speed and coarser feed than finer teeth, and cuts stock more easily and quickly.

Newton (Consolidated) Works recommend a high speed and light feed for steel low in carbon and manganese to keep the chip thin as possible. Up to 35-point carbon, use 60 to 65 feet per minute for solid blades; from 35- to 50-point carbon, 55 to 60 feet per minute and less feed. Above 50-point carbon, use inserted tooth saws. With inserted tooth saws speeds can be from 50 to 80 feet per minute on 50- to 70-point carbon, but only on heavy, rigid machines.

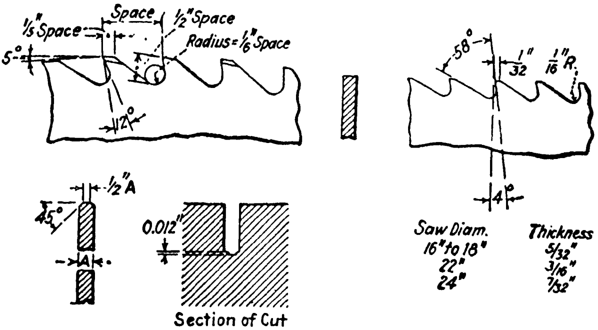


FIG. 30.—Atkins Tooth

For cutting sprues in steel foundries a solid-tooth saw with a speed of 55 feet per minute and a feed of ¼ to ⅜ inch per minute is recommended.

The work should be flooded at all times with any good cutting compound which does not rust.

Hack Saws (Starret)

Hack saws for use in hand frames vary from 6 to 12 inches in length and from 18 to 32 teeth per inch in most cases. They are usually $\frac{7}{16}$ or ½ inch wide and 0.025 inch thick. Saws for use in power machines are made from 10 to 24 inches long and with from 8 to 24 teeth per inch. They are from ⅝ to 1 inch wide and from 0.030 to 0.065 inch thick. Some have stiff backs, while others are made flexible.

For general use in hand frames, makers recommend 18 teeth per inch. For tubing and thin metals, 24 to 32 teeth per inch. Saws for use in power machines vary in the same way and with the speed and size of the machine.

Power-machine saws should run about 50 strokes per minute dry or from 65 to 100 strokes with compound. Too much weight dulls a new saw quickly. Use fine saws for pipes, tubes, thin metal, brass, copper, or very hard steel.

Saw length usually means distance between holes.

HACK-SAW BLADES

HACK-SAW BLADE CHART (STARRET)

HACK-SAW BLADES

Type	No. Teeth	Wide in Inches	Thick in Inches	Length in Inches	Material to Cut
Hand	14	9/16	0.028	8–13	Cast iron, cold rolled steel, soft steel, bronze, aluminum, hard rubber, fiber paper
	16	9/16	0.025	12–14	Heavier material than 18 tooth
	18	1/2	0.025	8–13	Tool steel, hard metals, light structural shapes, general purpose
	24	1/2	0.025	8–11	Tubing, wrought pipe, C.B., copper, draw rod el. casing, X light structural metal trim, 16–18 g. sheet metal
	32	1/2	0.025	8–11	Thin copper and brass tubing, sheet metal, 19 and thin metal trim
Power D	4	1 1/2	0.065	17–18	Large size cold rolled steel and shaft
D	6	1 1/8	0.048	12–24	Cold rolled steel or shafting over 2 inches
D	8	1	0.048	12–24	Cold rolled steel or shafting over 2 inches
D	8	1	0.065	17–32	Cold rolled steel or shafting under 2 inches
D	8	1 1/4	0.048	12–24	Cold rolled steel or shafting under 2 inches
C	10	3/4	0.048	10–17	Cast iron, machine steel, bronze
D	10	1	0.065	14–32	Cast iron, machine steel, bronze
C	10	1	0.048	10–24	Cold rolled steel and shaft
D	10	1 1/4	0.048	17–18	Cold rolled steel and shaft over 2 inches
D	10	1 1/2	0.065	18–30	Cold rolled steel and shaft under 2 inches
C	12	3/4	0.048	10–18	Cast iron machine steel, bronze
C	12	1	0.048	14–18	Cast iron machine steel, bronze
D	12	1	0.048	10–24	Tool steel and hard metals
B	14	5/8	0.028	10–18	Cutting stock 2 inches under, tool steel, wrought iron, cast iron, copper and brass solid
B	14	3/4	0.032	12–20	Cutting stock 2 inches over, tool steel, wrought iron, cast iron, copper and brass solid
B	14	3/4	0.042	12–14	Cutting stock 2 inches under, tool steel, wrought iron, cast iron, copper and brass solid
D	14	7/8	0.065	17–18	Pipe and structural shapes
C	14	1	0.042	12–17	Tool steel and hard metals
B	18	5/8	0.028	12–14	Iron pipe, copper and brass tube, not under 16 g. or over 2 inches diameter
B	18	3/4	0.032	12–14	Iron pipe, copper and brass tube, not under 16 g. or more than 2 inches diameter
B	18	1	0.048	14–18	Structural shapes, brass and copper tube

B = Light gravity feed—slow speed   C = Regular gravity feed machine   D = Heavy gravity or positive feed machine

This table helps to select the proper blade for practically all

HACK- AND BAND-SAW BLADES FOR VARIOUS MATERIALS (ATKINS)

Material to Be Cut	All Hard Hand Blades				All Hard for Light-power Machines, 50 Strokes per Min.					All Hard for Heavy-power Machines					All Hard-band High-speed Saws			
	Pitch	Gauge	Width	Length	Pitch	Gauge	Width	Length	Speed per Min.	Pitch	Gauge	Width	Length	Speed in Strokes per Min.	Pitch	Gauge	Width	Speed, Feet per Minute
Aluminum	14	22	9/16	8 to 16	14	All No. 21 gauge	All ½ inch width	All 10 to 17 inches length	All 50 strokes per minute	8	All No. 18 gauge	All 1 inch width	12 to 18	60	7	All No. 21 gauge	½ to ¾	1,000
Angles, T's Channels	24	23	½	8 to 12	18					18			12 to 24	70	9		½ to ¾	4,000
Babbitt	16	23	9/16	8 to 14	14					12			10 to 24	70				
Brass	18	23	½	8 to 12	18					18			12 to 24	70	8		½ to ¾	1,000
Brass Pipe	24	23	½	8 to 12	18					18			12 to 24	70	9		½ to ¾	1,000
Bronze	14	22	9/16	8 to 16	14					18			12 to 24	70	8		½ to ¾	1,000
Cable, Insulated	18	23	½	8 to 12	..					..								
Cast Iron	18	22	⅝	12 to 20	18					12			10 to 24	70				
Cold Rolled Steel	14	22	9/16	8 to 16	14					10			10 to 24	80				
Conduit	24	23	½	8 to 12	18					..								
Copper	14	22	⅝	8 to 20	14					8			12 to 18	70	6		½ to ¾	1,000
Drill Rod	24	23	½	8 to 12	18					12			10 to 24	60				
Fibre, Hard Rubber	14	22	9/16	8 to 16	..					..								
Machine Steel	14	22	9/16	8 to 16	14					10			10 to 24	80				
Ornamental Iron	24	23	½	8 to 12	18					18			12 to 24	70				
Pipe—Iron and Steel	24	23	½	8 to 12	18					18			12 to 24	70				
Rails	14	22	⅝	8 to 20	14					10			10 to 24	70				
Sheet Metal, under 18 Gauge	32	23	½	8 to 12	..					..					9		½ to ⅝	4,000
Tool Steel	18	23	½	8 to 12	14					14			12 to 24	50				
Tubing, Thin	32	23	½	8 to 12	18					18			12 to 24	70	9		½ to ⅝	4,000
Tubing, over 18 Gauge	24	23	½	8 to 12	18					18			12 to 24	70				

SIZES OF SCREW-SLOTTING CUTTERS

STANDARD KEYWAYS IN ALL THESE CUTTERS

These cutters have a fine pitch of teeth especially adapted to the slotting of screw heads and similar work. They are not ground on the sides.

Carbon steel cutters 2¾ inches diameter have seventy-two teeth, 2¼ inches diameter, sixty teeth and 1¾ inches diameter, ninety teeth. High-speed steel cutters 2¾ inches diameter have fifty-six teeth.

High-speed steel cutters listed are furnished with 1 inch holes only.

Diameter of Screw Head to Be Slotted, Inches	Gauge Number, American Standard	Thickness of Cutter, Inches	Diameter Cutter, Inches	Hole, Inches	Diameter of Screw Head to Be Slotted, Inches	Gauge Number American Standard	Thickness of Cutter, Inches	Diameter of Cutter, Inches	Hole, Inches
1 5/16	5	0.182	2¾	1	....	15	0.057	2¼	⅝
1⅛	6	0.162	2¾	1	....	16	0.051	2¼	⅝
1	7	0.144	2¾	1	....	17	0.045	2¼	⅝
⅞	8	0.128	2¾	¾, 1	....	18	0.040	2¼	⅝
¾ to 13/16	9	0.114	2¾	¾, 1	....	19	0.035	2¼	⅝
⅝	10	0.102	2¾	¾, 1	3/16	20	0.032	2¼	⅝
....	11	0.091	2¾	¾, 1	⅛	21	0.028	2¼	⅝
½ to 9/16	12	0.081	2¾	¾, 1	....	22	0.025	2¼	⅝
....	13	0.072	2¾	¾, 1	....	23	0.023	2¼	⅝
⅜ to 7/16	14	0.064	2¾	½ ⅝ ¾	....	24	0.020	2¼	⅝
11/32	15	0.057	2¾		....	25	0.018	2¼	⅝
5/16	16	0.051	2¾		....	26	0.016	2¼	⅝
....	17	0.045	2¾		....	27	0.014	2¼	⅝
¼ to 9/32	18	0.040	2¾		....	28	0.012	2¼	⅝
3/16 to 7/32	19	0.035	2¾		....	30	0.010	2¼	⅝
....	20	0.032	2¾		....	32	0.008	2¼	⅝

$\frac{1}{8}$	21	0.028	$2\frac{3}{4}$	1	....	34	0.006	$2\frac{1}{4}$	$\frac{5}{8}$
$\frac{1}{8}$	22	0.025	$2\frac{3}{4}$		$\frac{3}{8}$	14	0.064	$1\frac{3}{4}$	$\frac{5}{8}$
....	23	0.023	$2\frac{3}{4}$		$\frac{11}{32}$	15	0.057	$1\frac{3}{4}$	$\frac{5}{8}$
....	24	0.020	$2\frac{3}{4}$		$\frac{5}{16}$	16	0.051	$1\frac{3}{4}$	$\frac{5}{8}$
....	25	0.018	$2\frac{3}{4}$		$\frac{9}{32}$	17	0.045	$1\frac{3}{4}$	$\frac{5}{8}$
....	26	0.016	$2\frac{3}{4}$	$\frac{3}{4}$, 1	$\frac{1}{4}$	18	0.040	$1\frac{3}{4}$	$\frac{5}{8}$
....	27	0.014	$2\frac{3}{4}$	$\frac{3}{4}$, 1	$\frac{7}{32}$	19	0.035	$1\frac{3}{4}$	$\frac{5}{8}$
....	28	0.012	$2\frac{3}{4}$	$\frac{3}{4}$, 1	$\frac{3}{16}$	20	0.032	$1\frac{3}{4}$	$\frac{5}{8}$
....	30	0.010	$2\frac{3}{4}$	$\frac{3}{4}$, 1	$\frac{1}{8}$	21	0.028	$1\frac{3}{4}$	$\frac{5}{8}$
....	32	0.008	$2\frac{3}{4}$	$\frac{3}{4}$, 1	....	22	0.025	$1\frac{3}{4}$	$\frac{5}{8}$
....	34	0.006	$2\frac{3}{4}$	$\frac{3}{4}$, 1	....	23	0.023	$1\frac{3}{4}$	$\frac{5}{8}$
....	10	0.102	$2\frac{1}{4}$	$\frac{5}{8}$	....	24	0.020	$1\frac{3}{4}$	$\frac{1}{2}$, $\frac{5}{8}$
....	11	0.091	$2\frac{1}{4}$	$\frac{5}{8}$	....	25	0.018	$1\frac{3}{4}$	$\frac{1}{2}$, $\frac{5}{8}$
....	12	0.081	$2\frac{1}{4}$	$\frac{5}{8}$	....	26	0.016	$1\frac{3}{4}$	$\frac{1}{2}$, $\frac{5}{8}$
....	13	0.072	$2\frac{1}{4}$	$\frac{5}{8}$	....	27	0.014	$1\frac{3}{4}$	$\frac{1}{2}$, $\frac{5}{8}$
....	14	0.064	$2\frac{1}{4}$	$\frac{5}{8}$	....	28	0.012	$1\frac{3}{4}$	$\frac{1}{2}$, $\frac{5}{8}$
					....	30	0.010	$1\frac{3}{4}$	$\frac{1}{2}$, $\frac{5}{8}$
					....	32	0.008	$1\frac{3}{4}$	$\frac{1}{2}$, $\frac{5}{8}$
					....	34	0.006	$1\frac{3}{4}$	$\frac{1}{2}$, $\frac{5}{8}$

TABLE 13.—CUTTING SPEEDS[1] FOR HIGH-SPEED SAWS

Material	Peripheral Speed, in Feet per Minute	Lubricant
S.A.E. 3245	40 to 45	Sulphur-base oil
S.A.E. 3130	50 to 60	Sulphur-base oil
Annealed tool steel Untreated alloy steel	60 to 70	Sulphur-base oil
Cast iron	70 to 90	None
Soft machine steel Cold-rolled steel Malleable castings	90 to 160	Soluble oil
Bronze	600	None
Brass	800	Lard oil ¾, kerosene ¼
Aluminum	1,000	Kerosene

Feeds, in Inches per Minute for Different Materials

Saw Thickness	Depth of Cut	Tool Steel Cr. Ni Steel	Cold-Rolled Steel	Cast Iron	Brass	Aluminum
1/32	1/16	½	¾ to 1	¾ to 1	1	1½
1/16	⅛	¾ to 1	1⅝ to 2	1⅝ to 2	2	2½
⅛	¼	1 to 1½	2 to 3	3 to 4	5	8
3/16	¼	1 to 1¼	2 to 3	3 to 4	5	8
¼	¼	1½ to 2	2½ to 3½	3 to 4	10 to 20	12 to 24

Feet per Minute..	40	50	60	70	80	90	100	125	150	175	200	300	400	500	750	1,000
Diameter of Saw	Revolutions per Minute															
½	306	382	459	535	611	688	764	955	1,146	1,337	1,528	2,292	3,056	3,820	5,730	7,640
⅝	245	306	367	428	489	550	612	765	917	1,071	1,224	1,836	2,448	3,060	5,190	6,120
¾	203	254	306	357	408	458	508	635	764	889	1,016	1,524	2,032	2,540	3,810	5,080
⅞	175	219	262	306	349	393	438	548	655	767	875	1,314	1,752	2,190	3,285	4,380
1	153	191	229	267	306	344	382	477	573	668	764	1,146	1,528	1,910	2,865	3,820
1½	102	127	153	178	204	229	255	318	382	445	509	764	1,020	1,275	1,912	2,550
2	76	95	115	134	153	172	191	238	286	334	382	573	764	995	1,432	1,910
2½	61	76	91	107	122	138	153	191	229	267	305	458	611	764	1,147	1,530
3	50	63	76	89	102	115	127	159	191	222	254	382	509	636	952	1,270
3½	43	54	65	76	87	98	109	136	164	191	218	327	436	545	818	1,090
4	38	47	57	66	76	85	95	119	143	167	191	286	382	477	716	955
4½	34	42	50	59	67	76	84	106	127	145	169	254	339	424	636	849
5	30	38	45	53	61	68	76	95	115	133	152	229	305	382	573	764
5½	27	34	41	48	55	62	69	86	104	121	138	208	277	347	512	694
6	25	31	38	44	50	57	63	79	95	111	127	191	254	318	477	636
6½	23	29	35	41	47	52	58	73	88	102	117	176	235	293	440	587
7	21	27	32	38	43	49	54	68	81	95	109	163	218	272	409	545
7½	20	25	30	35	40	45	50	63	76	89	101	152	203	254	382	509
8	19	23	28	33	38	43	47	59	71	83	95	143	191	238	358	477
9	17	21	25	29	34	38	42	53	63	74	84	127	169	212	318	424
10	15	19	22	26	30	34	38	47	57	66	76	114	152	191	286	382
11	13	17	20	24	27	31	34	43	52	60	69	104	138	173	260	347
12	12	15	19	22	25	28	31	39	47	55	63	95	127	159	239	318

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[1] These data can be used for either cutting-off or slotting operations, and are published through the courtesy of the Morse Twist Drill & Machine Company.

TABLE 14.—CIRCULAR SAWS FOR CUTTING BRASS, COPPER, ALUMINUM, AND OTHER SOFT-METAL SHEETS

Simonds Saw and Steel Company's circular saws for cutting brass, copper, aluminum, and other soft metals in sheet form and for tubing and light cuts are made of carbon steel and ground concave on the sides for clearance and tempered to be sharpened with a file. These saws are also flat ground with teeth set and filed.

Diameter of Saw, in Inches	Thickness					Holes, in Inches	Teeth per Saw	Teeth per Inch
4	$\frac{1}{32}$	$\frac{3}{64}$	$\frac{1}{16}$	..	..	½ and larger	100	8
							120	10
5	$\frac{1}{32}$	$\frac{3}{64}$	$\frac{1}{16}$	..	..	¾ and larger	130	8
							150	10
							190	12
6	$\frac{1}{32}$	$\frac{3}{64}$	$\frac{1}{16}$	..	..	¾ and larger	70	4
							110	6
							150	8
							190	10
8	$\frac{1}{32}$	$\frac{3}{64}$	$\frac{1}{16}$	..	..	¾ and larger	100	4
							150	6
							200	8
10	..	$\frac{3}{64}$	$\frac{1}{16}$	$\frac{5}{64}$	$\frac{3}{16}$	¾ and larger	130	4
							190	6
							250	8
12	..	..	..	$\frac{5}{64}$	$\frac{3}{16}$	1 and larger	150	4
							220	6

NOTE.—Speeds for above saws are figured on a rim speed of 2,500 feet per minute. On extremely light work this speed can be slightly increased. On heavier cuts the speed should be reduced.

Saws for Brass or Copper

These are usually 10 inches or less in diameter and run from 200 to 1,200 revolutions per minute, varying with the composition being cut. A fine stream of lard oil makes a good cutting compound for this type of saw, but when quick light cuts are being made, a cake of beeswax or soap pushed on to the saw occasionally, reduces friction while cutting and makes the part cut off much cleaner to handle. Some of these saws are hard and ground concave. Others are ground flat and are of a low-enough temper to permit being set and filed.

Saws for Aluminum

These have radial teeth set and filed. Saws for aluminum have the cutting edge of tool radial. They are soft enough to be set and filed.

Saws for Celluloid

These saws are about 12 inches in diameter, of thin gage, and have very fine pitch to center teeth.

Saws for Electrotypes

These saws come in sizes 5 to 10 inches in diameter; teeth are set and filed or swaged, or saws are concave ground. Teeth are made about ¼ inch space and pitched to the center. These saws are made for cutting both the electrotype metal and the wood mount.

Saws for Hard Rubber

These saws are concave ground and have a regular pitch to center, backed off metal saw tooth. About ¼ inch pitch.

Inserted-Tooth Metal Saws

Inserted-tooth metal saws with high-speed steel teeth are adapted for use in shops where heavy material is to be cut. Thin stock can be cut by nesting or cutting two or more pieces at a time. Simonds Saw and Steel Company states that no matter what the size of the inserted-tooth metal saw, the rim speed should not exceed 40 feet per minute. They say in regard to the feed:

"The amount of feed depends largely on the degree of hardness of the stock. The harder the stock the greater the strain on the saw and on the machine and the harder and finer the grain of the stock the more power it takes to drive the saw through it and the more quickly the saw will become dull. If the stock is very soft, tough, or stringy, the clearance must be perfect and a considerable amount of hook must be maintained and the chips broken up, or the material will cling to the face of the tooth and cause the saw to run hard or stick in the cut.

TABLE 15.—SIMONDS NO. 000 INSERTED-TOOTH METAL SAW

Diameter, in Inches	Thickness of Plate Inches	Kerf Inches	No. of Teeth	Diameter, in Inches	Thickness of Plate Inches	Kerf Inches	No. of Teeth
10	$\frac{3}{16}$	$\frac{1}{4}$	32	30	$\frac{1}{4}$	$\frac{5}{16}$	94
12	$\frac{3}{16}$	$\frac{1}{4}$	44	30	$\frac{5}{16}$	$\frac{3}{8}$	94
14	$\frac{3}{16}$	$\frac{1}{4}$	52	30	$\frac{3}{8}$	$\frac{15}{32}$ or $\frac{7}{16}$	94
16	$\frac{3}{16}$	$\frac{1}{4}$	60	32	$\frac{1}{4}$	$\frac{5}{16}$	100
18	$\frac{3}{16}$	$\frac{1}{4}$	60	32	$\frac{5}{16}$	$\frac{3}{8}$	100
20	.160	$\frac{7}{32}$	62	32	$\frac{3}{8}$	$\frac{15}{32}$ or $\frac{7}{16}$	100
20	$\frac{3}{16}$	$\frac{1}{4}$	62	34	$\frac{1}{4}$	$\frac{5}{16}$	106
20	$\frac{1}{4}$	$\frac{5}{16}$	62	34	$\frac{5}{16}$	$\frac{3}{8}$	106
20	$\frac{5}{16}$	$\frac{3}{8}$	62	34	$\frac{3}{8}$	$\frac{15}{32}$ or $\frac{7}{16}$	106
21	.160	$\frac{7}{32}$	66	36	$\frac{1}{4}$	$\frac{5}{16}$	114
22	.160	$\frac{7}{32}$	70	36	$\frac{5}{16}$	$\frac{3}{8}$	114
22	$\frac{3}{16}$	$\frac{1}{4}$	70	36	$\frac{3}{8}$	$\frac{15}{32}$ or $\frac{7}{16}$	114
22	$\frac{1}{4}$	$\frac{5}{16}$	70	37	$\frac{1}{4}$	$\frac{5}{16}$	116
22	$\frac{5}{16}$	$\frac{3}{8}$	70	38	$\frac{5}{16}$	$\frac{3}{8}$	120
24	.160	$\frac{7}{32}$	76	38	$\frac{3}{8}$	$\frac{15}{32}$ or $\frac{7}{16}$	120
24	$\frac{3}{16}$	$\frac{1}{4}$	76	40	$\frac{5}{16}$	$\frac{3}{8}$	126
24	$\frac{1}{4}$	$\frac{5}{16}$	76	40	$\frac{3}{8}$	$\frac{15}{32}$ or $\frac{7}{16}$	126
24	$\frac{5}{16}$	$\frac{3}{8}$	76	42	$\frac{5}{16}$	$\frac{3}{8}$	132
26	$\frac{3}{16}$	$\frac{1}{4}$	82	42	$\frac{3}{8}$	$\frac{15}{32}$ or $\frac{7}{16}$	132
26	$\frac{1}{4}$	$\frac{5}{16}$	82	44	$\frac{5}{16}$	$\frac{3}{8}$	138
26	$\frac{5}{16}$	$\frac{3}{8}$	82	44	$\frac{3}{8}$	$\frac{15}{32}$ or $\frac{7}{16}$	138
26	$\frac{3}{8}$	$\frac{15}{32}$ or $\frac{7}{16}$	82	46	$\frac{5}{16}$	$\frac{3}{8}$	144
28	$\frac{3}{16}$	$\frac{1}{4}$	88	46	$\frac{3}{8}$	$\frac{15}{32}$ or $\frac{7}{16}$	144
28	$\frac{1}{4}$	$\frac{5}{16}$	88	48	$\frac{5}{16}$	$\frac{3}{8}$	150
28	$\frac{5}{16}$	$\frac{3}{8}$	88	48	$\frac{3}{8}$	$\frac{15}{32}$ or $\frac{7}{16}$	150
28	$\frac{3}{8}$	$\frac{15}{32}$ or $\frac{7}{16}$	88	50	$\frac{5}{16}$	$\frac{3}{8}$	158
29	$\frac{3}{16}$	$\frac{1}{4}$	92	50	$\frac{3}{8}$	$\frac{15}{32}$ or $\frac{7}{16}$	158

"We advise running a saw for the first cut of two or three inches after it has been sharpened or when it is put on new, at about one-half the feed to be maintained. This allows the burr thrown up in the sharpening to smooth off and lessens the liability of breakage which possibly might be caused by a tooth left a little high."

Discs for Cutting Metals

Discs (circular plates without teeth) are used for cutting cold iron or steel. Henry Disston and Sons, Inc., says these discs are run at a high rate of speed, about 24,000 feet per minute rim motion, and cut by friction. In size they vary from 14 inches, 10 gage, to 50 inches diameter 3 gage or $\frac{17}{64}$ inch thick. They are used in foundries, forge shops, and metalworking plants to cut such work as rails, beams, bar stock, etc.

These friction discs, as they are called, eat their way through the metal by a process of fusing or melting the stock. The great speed at which they run creates intense heat which melts away the stock in front of the disc edge. Disston states that a disc was used in Sheffield running at 86,000 feet per minute rim speed for cutting 6-inch armor plate. Owing to the creation of such a volume of heat, it was necessary to play a heavy stream of water on the disc continuously to prevent it from fusing with the stock that is being cut.

For cutting hot iron and steel at high speed, solid-tooth circular saws (sometimes known as "hot" saws), are used. These range in size from 14 inches diameter 10 gage (or $\frac{1}{8}$ inch thick) to 50 inches diameter 3 gage (or $\frac{17}{64}$ inch thick). The teeth vary from $\frac{3}{8}$ to $\frac{7}{8}$ inch spacing. Hot saws are run at slightly lower speeds than friction discs, about 20,000 feet rim motion, according to Disston.

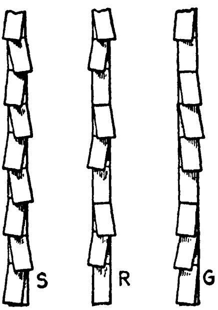


FIG. 31.—Three "Sets" in Saw Teeth

Use of Band and Hack Saws

The use of band saws for cutting metals and other materials used in machine building and similar industries is increasing. As with other tools it is necessary to select the proper saw for the work to be done and to run it at the correct speed. The following table gives the latest suggestions of Henry Disston and Sons, Inc. This table gives the number of teeth per inch and the cutting speed in feet per minute. In every case the temper and set recommended by the maker should be followed for best results. As these designations are arbitrary, it is best to consult the maker concerning these points for the work to be done. See Fig. 31.

The teeth are punched. Spring-tempered metal-cutting band saws are recommended for cutting the softer materials in thin gages, and they can be resharpened.

The "set" of the teeth is important. Straight set, that is, *S* set, has one tooth set to the right and the next to the left as shown in Fig. 31. The raker set, that is, the *R* set, has one tooth straight (the straight tooth is the raker tooth to act as a cleaner and a chip breaker), one tooth to the left, next tooth to the right. The group set *G* set has one set of waves to the right and the next set to the left to give the smallest possible tooth spacing.

The gage of a saw depends upon the diameter of the wheel, because the diameter determines the radius of the bend the saw must make during each revolution.

Size of Wheel, Inches	Gage of Saw, Stubbs	Widths, in Inches
12	25—0.020″	3/8 to 1/2
15	23	3/8 to 1/2
18	23 0.025″	3/8 to 1/2
20	23	3/8 to 1/2
24	21	1/2 to 5/8 to 3/4
30	21 0.032″	1/2 to 5/8 to 3/4
36	21	1/2 to 5/8 to 3/4
36	20—0.035″	1

There are two factors which determine the width of a metal-cutting band saw:

1. The greater the feed, the wider and heavier must be the saw to stand it. It is impractical to give a table of widths and feeds because of the wide range of operating conditions and the long list of materials to be cut.
2. The smaller the radius of the curvature to be cut, the narrower the saw must be.

WIDTH OF BAND SAW, IN INCHES	MINIMUM RADIUS THAT CAN BE CUT, IN INCHES
1/4	3/4
3/8	1 1/2
1/2	2 1/4
5/8	3
3/4	4 1/2
1	8

Saws must be tensioned over the wheels and each machine has a tension adjustment. The following table gives the tension in pounds for the different width blades:

WIDTH OF BLADE, IN INCHES	TENSION OR STRAIN, IN POUNDS
1/4	55
3/8	100
1/2	160
5/8	200
3/4	240
1	320

To obtain full cutting efficiency of a band saw blade, careful attention should be given to proper adjustment of the guide rolls as in Fig. 32.

Cutting compound is not usually considered necessary except for cold-rolled, machinery, nickel, and structural steels. This includes the use of band saws for cutting out dies in the toolroom and similar uses where they save time in many cases.

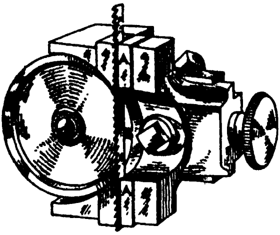


FIG. 32.—Adjustment of Band-Saw Guide

BAND SAWS

Band saws should be removed from the machine or have the tension released when not in use. This is very important during the winter months when there are extreme changes in temperature. The tables give suggestions as to saws and speeds.

TABLE 16.—RECOMMENDED SPECIFICATIONS FOR CUTTING SPECIFIC MATERIALS WITH DISSTON METAL-CUTTING BAND SAWS

Material	Number of Teeth per Inch*	Set	Speed of Blade, in Feet per Minute*
Aluminum alloy (pistons, moulding)	12 to 14	*R*	100 to 150
Aluminum sheets	8 to 10	*S*	1,000 to 3,000
Asbestos sheets (thin gages, transite, asbestos board, etc.)	8 to 12	*S*	150 to 200
Babbitt	10 to 14	*R*	1,000 to 1,500
Bakelite	8 to 10	*S*	800 to 1,000
Brass cast, soft (screw stock, red-yellow brass, etc.)	10 to 14	*S*	700 to 1,500
Brass cast. hard	10 to 14	*R*	200 to 500
Brass sheets and tubing	14	*S* or *G*	700 to 1,500
Bronze (manganese, tobin, etc.)	10 to 14	*R*	150 to 350
Bronze castings	10 to 14	*S* or *R*	300 to 800
Carbon tool steel	12 to 14	*R*	100 to 150
Cast iron	12 to 14	*R*	100 to 150
Cold-rolled steel	10 to 12	*R*	150 to 200
Copper	8 to 12	*S*	500 to 1,000
Drill rod	14	*R*	80 to 150
Fiber	8 to 10	*S*	300 to 500
High-speed steel	12 to 14	*R*	90 to 125
Hose—metallic	18 to 22	*G*	500 to 1,000
Iron bars	12 to 14	*R*	100 to 150
Iron sheets	14 to 18	*R*	100 to 250
Machinery steel	10 to 14	*R*	100 to 150
Malleable iron	12 to 14	*R*	150 to 200
Metal wood	14	*R*	1,000 to 2,000
Mica	10 to 12	*S*	300 to 600
Monel metal	10 to 12	*R*	125 to 200
Pipe	14 to 18	*R* or *S*	100 to 200
Rubber—hard	10 to 14	*S*	150 to 200
Slate	10 to 14	*S*	100 to 150
Structural steel	10 to 14	*R* or *G*	90 to 150
Tubing—steel	14 to 18	*R* or *G*	100 to 150

* Generally speaking, the greater the number of teeth, the lower the speed, and *vice versa*. Operating conditions vary too widely to make all these recommendations without variations. Actual operating experience on specific machines gives the only correct answer.

HAND HACK SAWS

The most commonly used blade for general hand hack-saw work has 18 teeth per inch. Blades with 24 and 32 teeth are used for tubing, sheet metal, and all thin-walled stock, and drill rod.

Machine speeds can be from 60 to 100 strokes per minute, depending on the blade and the work. Hand blades should not be run faster than 40 to 60 strokes per minute. There should be plenty of pressure on the cutting stroke and the blade lifted slightly on the return. Blade breakage is attributed to the following causes:

Excessive feed pressure, especially on light or soft stock.

Selection of too coarse a tooth for light stock. Tooth breakage is largely followed by body breakage.

Overstrain or overtensioning of the blade in the frame.

Ends pull out or body breaks.

Failure to relieve tension on blade when not in use. Blade will often snap when standing idle.

Too little tension, blade buckles and breaks.

Machine may be out of line, causing blade to run in or out, eventually breaking it.

Selection of too light a gage in the blade for the machine in which it is used.

Holding Work for Cutting-Off Saws

Work to be cut with saws should be held firmly to avoid breakage of saws. Figure 33 shows several methods of holding work to be cut.

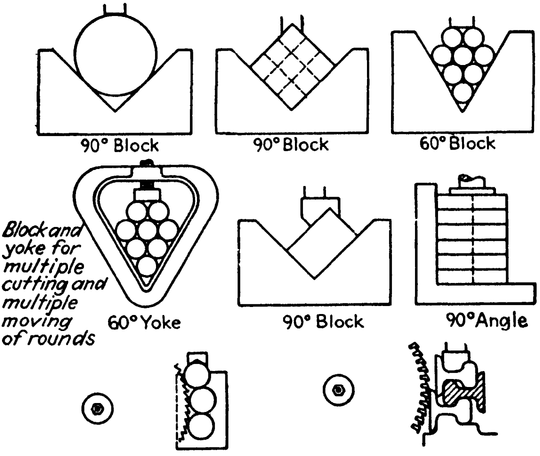


FIG. 33.—Holding Work for Sawing

GRINDING MILLING CUTTERS

The following illustrations and tables show the recommendations of the Cincinnati Milling Machine Company in the grinding of milling cutters of various types. These cover the cutters most in use.

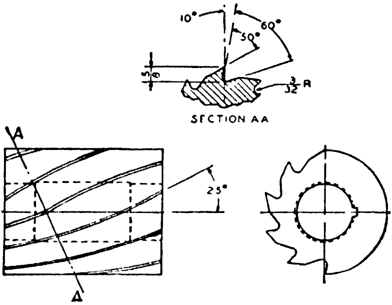


FIG. 34.—Helical Milling Cutter

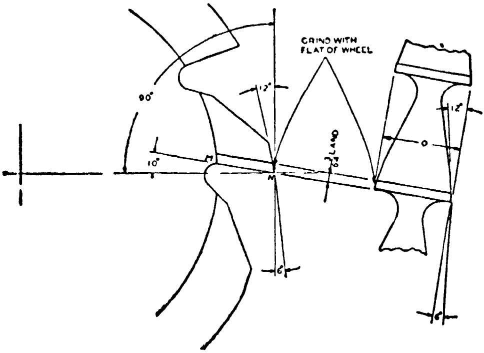


FIG. 35.—Straight-Tooth Cutter

The diagrams, from Figs. 34 to 38 inclusive, show the methods and angles that have proved satisfactory in practice.

These methods have been worked out after much experimenting and can be easily used on modern cutter-grinding machines.

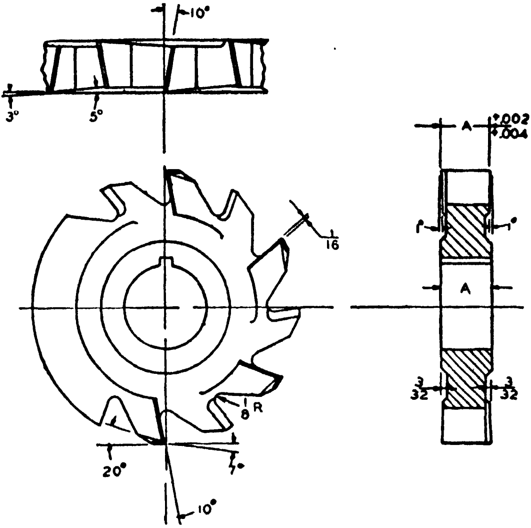


FIG. 36.—Stagger-Tooth Cutter

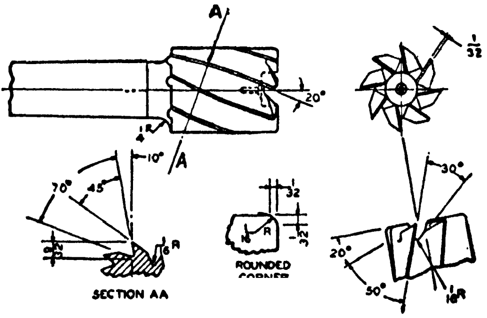


FIG. 37.—End Mill

Helical teeth are shown on several of the cutters, the helix angle being given in each case by the line at right angles to the teeth. Both solid end mills with shank and shell end mills are shown in Figs. 37 and 38.

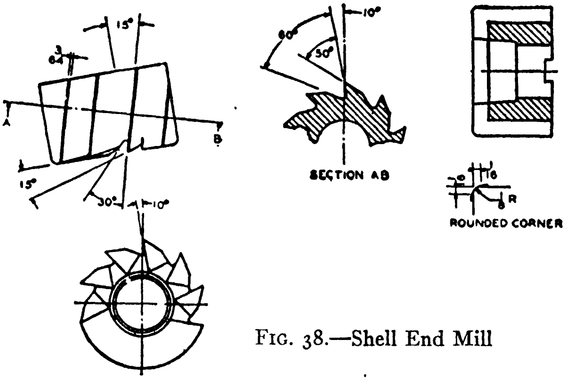


Fig. 38.—Shell End Mill

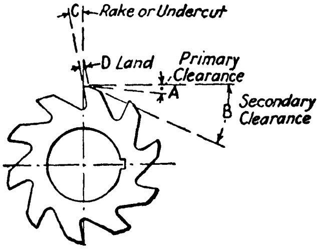


TABLE 17.—CLEARANCE ANGLES FOR MILLING CUTTERS

Material To Be Machined	Clearance Angle A, Degrees	Clearance Angle B, Degrees	Rake Angle C, Degrees	Land D, Inches
Low carbon steel	5 to 7	30	15	$\frac{1}{32}$
High carbon steel and tool steel	4 to 5	30	10	$\frac{1}{32}$
Steel castings	6 to 7	30	15	$\frac{1}{32}$
Cast iron	3 to 6	30	10	$\frac{1}{32}$
Cast brass	10 to 12	30	10	$\frac{1}{32}$
Soft bronze (60 Brinell or less)	10 to 15	30	10	$\frac{1}{32}$
Medium bronze (60 to 90 Brinell)	6 to 7	30	10	$\frac{1}{32}$
Hard bronze (above 90 Brinell)	4 to 5	30	10	$\frac{1}{32}$
Copper	12 to 17	30	10	$\frac{1}{32}$
Aluminum	10 to 12	30	10	$\frac{1}{32}$

The table showing clearance angles for cutters for different materials on page 476 will be found of great value in securing maximum results from cutters. Table 18 is especially for helical cutters.

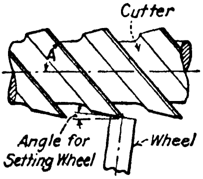


TABLE 18.—ANGLE FOR SETTING WHEEL TO OBTAIN CLEARANCE ANGLE OF 3 TO 10° ON HELICAL CUTTERS

Helix Angle A	Clearance Angle Desired							
	3°	4°	5°	6°	7°	8°	9°	10°
30°	1½	2	2½	3	3½	4	4½	5
35°	1¾	2¼	3	3½	4	4½	5¼	5¾
40°	2	2½	3¼	4	4½	5¼	5¾	6½
45°	2	2¾	3½	4¼	5	5¾	6½	7¼
50°	2¼	3	3¾	4½	5½	6¼	7	7¾
55°	2½	3¼	4	5	5¾	6½	7½	8¼
60°	2½	3½	4¼	5¼	6	7	7¾	8¾
65°	2¾	3¾	4½	5½	6½	7¼	8¼	9
70°	2¾	3 8/4	4¾	5¾	6½	7½	8½	9½
75°	3	3¾	4¾	5¾	6¾	7¾	8¾	9¾

The proper sharpening of the periphery teeth of staggered-tooth cutters involves three definite steps, as follows:

1. Mount the cutter on an arbor between centers, and cylindrically grind teeth until all cutting edges are clean and sharp.

2. Mount cutter and arbor in the sharpening machine. The guide finger is mounted in a fixed position with relation to the grinding wheel. This guide finger must be beveled on the end to an angle that will closely match the spiral angle of one set of cutter teeth. It should project sufficiently beyond the grinding wheel so that the tooth to be sharpened rests on the finger before the wheel strikes the work. (Note the relative position of guide finger and grinding wheel in right-hand view, Fig. 39.)

The grinding wheel should be tilted slightly in relation to the axis of the cutter as shown in the upper left-hand view of Fig. 39. This is necessary in order to avoid striking other teeth than the one being sharpened and also provides cutting clearance for the wheel.

With everything in position the clearance is ground on all teeth having the same helix angle. The first cut should leave a very narrow (hairline) cylindrical land. The second and finishing cut then is very light and just enough to bring the teeth to a sharp edge.

3. After one set of teeth have been sharpened, another guide finger, beveled at the opposite angle, is substituted. This bevel conforms to the helix angle of the other set of teeth.

Sharpening is then carried on exactly as for the first set of teeth.

The circular grinding, mentioned before, is done for the sole purpose of serving as a guide for grinding all teeth the same height. It is, therefore, important that the finish sharpening cut brings out the sharp edge as described, and no more.

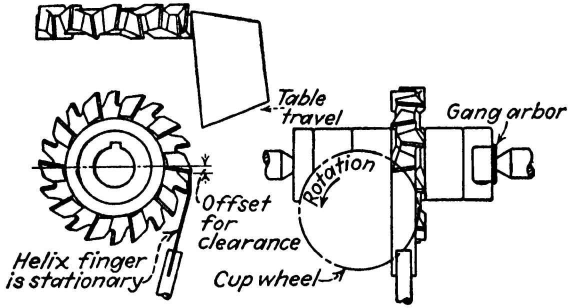


FIG. 39.—Grinding Staggered-Teeth Mills.

Staggered tooth cutters are made with a narrow flat land on the side teeth so as to maintain their width over a long period. Sharpening of side teeth is, therefore, seldom necessary.

When sharpening cutters, the grinding wheel should always rotate as shown in Fig. 39 so that the heat generated is carried away from the cutting edge.

SHARPENING OF STAGGERED-TOOTH UPPER AND LOWER MILLING CUTTERS

The sharpening of staggered-tooth cutters presents problems not found in the sharpening of the ordinary types of profile milling cutters. The National Twist Drill & Tool Co. says that Fig. 29 represents established practice as applied to the sharpening of these cutters.

CUTTING EDGES

There seems to be no doubt regarding the value of making cutting edges as smooth as possible. After grinding, the edges should be honed as thoroughly as possible. With the hone moved in the direction of the chip flow. Even with honing marks only a few micro-inches deep, the chips flow more easily *with* these marks than *across* them. Smooth cutting edges last longer and produce a better chip.

IMPORTANCE OF PROPER GRINDING OF CARBIDE CUTTERS

All who have studied the use of carbide cutters in milling agree that grinding and maintaining proper angles is most important. Wide variations in cutter life result from lack of proper care and inspection. Small cracks which result from improper grinding greatly reduce the life of any cutter.

Wheels.—Cincinnati Milling Machine Co. recommends the following diamond wheels, permanently mounted on wheel collets. Indicators should be used in checking runout of the face of cup wheels and the periphery of straight wheels. As the holes in wheels are 0.005 inch oversize, they can be adjusted to correct runout, which should not exceed 0.00025 inch. Vitrified bonded wheels may replace the present resinoid wheels. Preferred wheels are

1. *Roughing Wheels for Circle Grindings:* 6 inch diameter × $\frac{1}{2}$ inch wide, 100 grit, resinoid bond, 100 concentration, No. 100-B-100 $\frac{1}{8}$.
2. *Roughing Flaring Cup Wheel:* 10 degree tapered inside rim, $3\frac{1}{2}$ inch diameter, 100 grit, resinoid bond, 100 concentration, No. 100-B-100 $\frac{1}{8}$.
3. *Semifinish Flaring Cup Wheel:* 10 degree tapered inside run, $3\frac{1}{2}$ inch diameter, 180 grit, resinoid bond, 100 concentration, No. 100-B-100 — $\frac{1}{16}$.
4. *Semifinish flaring Cup Wheel:* 10 degree tapered inside rim, $3\frac{1}{2}$ inch diameter, 220 grit, resinoid bond, 100 concentration, No. 100-B-100 — $\frac{1}{16}$.
5. *Finish Flaring Cup Wheel:* 10 degree tapered inside rim, $3\frac{1}{2}$ inch diameter, 400 grit, resinoid bond, 100 concentration, No. 400-B-100 — $\frac{1}{16}$.

Accessories.—A double-ended diamond hand hone, 400 grit on one end, 500 grit on the other, resinoid bond, 100 concentration, $\frac{1}{32}$ inch diamond depth.

A diamond wheel dressing stick for 100 grit wheels. Pumice stone for dressing finishing wheels.

An 18 power watchmaker's magnifying glass.

A 40 to 50 power microscope with scale in eyepiece.

Use kerosene for cutting fluid in finishing operations.

Grinding Carbide Cutters:

Diamond wheels should be used exclusively for grinding carbide tips.

Use 100 grit straight wheels for circle grinding.

Use 100 grit cup wheels for general roughing where more than 0.002 inch of stock is to be removed.

Use 180 grit cup wheel for finishing face of tooth; also for semifinishing clearance lands and for grinding secondary clearance.

Use 400 grit cup wheel for finishing primary clearance lands.

Do not grind into body of cutter with diamond wheels as they will load up immediately. Carbide tip should project 0.040 to 0.060 inch beyond cutter body in original braze. Grinding wheel clearance should be provided in body of cutter for grinding face of tooth.

Diamond wheels should run from 5,000 to 5,500 feet per minute.

Roughing cuts should not remove more than 0.0004 inch per pass of wheel; semifinishing no more than 0.0002 inch and in finishing, 0.00015 inch.

The tip can be fed past the wheel at about 50 inches per minute in roughing and from 10 to 20 inches per minute in finishing.

Rotation of the grinding wheel *must* be *toward* the cutting edge.

In circle grinding use soluble oil in 100 to 1 mixture. Kerosene used in semifinishing and finishing will keep the wheel clean and free cutting. Wipe the wheel clean with a rag soaked in kerosene. Should the wheel load up, it can be opened up with pumice stone or with a dressing stick made specially for diamond wheels. Use the pumice stone on finishing wheels. Dress wheels as little as possible. Roughing wheels tend to burn and finishing wheels to load up.

The cutter grinder should use the 18 power watchmaker's glass to examine the carbide before grinding and during the sharpening operations. All cracks and flaws should be ground away in the roughing operation. All crater and abrasion marks must be ground away to secure maximum cutter life.

Indicate all the teeth for runout, after grinding. Clearance and body interference should also be carefully checked, especially in small diameter and for radius cutters.

Face and clearance lands should be carefully honed by hand after diamond grinding. The surface finish on a carefully ground and honed tooth should be between one and five micro-inches.

Before releasing the cutter to the shop inspect it carefully with the 40 to 50 microscope in a well-illuminated place.

In grinding, the cutter should be held in the same way as when it is in the milling machine. Shell end mills should be ground on their arbor.

Experience shows that when properly used, carbide cutters can be reconditioned by removing from 0.002 to 0.003 inch from tooth face and from 0.003 to 0.005 inch from the clearance lands. If more stock has to be removed the cutter has been used too long or the cutting conditions were not correct.

PRIMARY CLEARANCE ANGLES RECOMMENDED BY THE CINCINNATI MILLING MACHINE COMPANY

(Based on optimum results of research to June 27, 1944)

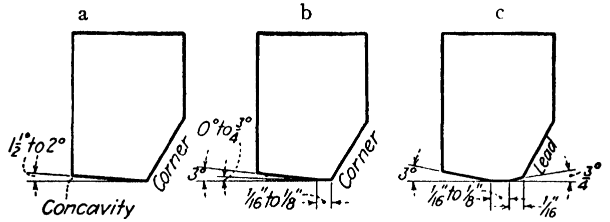
Type of Cutter	Primary Clearance Angles, in Degrees								
	Periphery			Corner			Face		
	Steel	C. I.	Al.	Steel	C. I.	Al.	Steel	C. I.	Al.
Face or side	3 to 4	5	10	3 to 4	5	10	2 to 3	4 to 5	10
Slotting	4 to 5	5	10	4 to 5	5	10	2	5	10
Saw	4 to 5	5	10	4 to 5	5	10	2	5	10

Maximum usable length of primary clearance land on periphery and corner is a function of the cutter diameter, clearance angle, and feed per tooth. A 1/32-inch land is suitable for general work with cutters 3 to 8 inches in diameter.

Secondary clearance angle on periphery and corner may be from 3 to 5 degrees more than the primary clearance.

Length of primary clearance land on face of cutter: in most cases the primary clearance may extend over the entire cutter tooth.

CONCAVITY OR FACE RELIEF, ON FACE OF CUTTER



For long tool life

For good work finish

For fine work finish where chatter occurs

Condition	Concavity Angle	Fig. No.
For long tool life	1½ to 2 degrees	*A*
For good work finish	½ to ¾ degrees	*B*
For fine work finish	0 land, 1/16 to 1/8 long	*B*
For fine work finish where chatter is encountered.	¾ × 1/16 plus 0 degree land 1/16 to 1/8 inch long	*C*

SECTION XI

GRINDING, HONING, AND LAPPING

GRINDING, PROCESSES, AND EQUIPMENT

Although grinding is usually considered a finishing operation, it is often employed as a complete machining process on work which can be ground down from rough condition without being turned or otherwise machined. Thus, many types of forgings and other parts are finished completely with the grinding wheel at appreciable saving of time and expense. Conditions that would control this practice would be the total amount of stock to be removed, the general shape of the piece, the types of machines available, etc.

Classes of grinding machines, in general, include the following:

Cylindrical, Internal, Centerless Grinders.—These are for straight cylindrical or taper external or internal work; thus, spindles, shafts, and similar parts are ground on cylindrical machines either of the common-center type or the centerless machine. Centerless grinding consists of passing the work between a regulating wheel and the grinding wheel without mounting on centers. Long shafts or other cylindrical parts are handled by passing longitudinally through the machine. Other pieces are finished by feeding directly against the wheel without end movement. This is called "plunge-cut grinding."

Internal Grinders.—These are for cylinder bores and similar operations where bores of all kinds are to be finished.

Surface Grinders.—These are for finishing all kinds of flat work or work with plane surfaces which may be operated upon either by the edge of a wheel or by the face of a grinding wheel. These machines may have reciprocating or rotating tables. Disc grinders also act upon the flat surfaces of the work piece; also belt grinders with flat abrasive belts are used for much flat work of suitable form and dimensions.

Various specialized types of machines are built for different classes of work such as crankshaft grinders (for cylindrical surfaces), precision bench grinders for tool work; chucking and hole grinders for finishing flat faces and the bore of a piece held in a chuck.

Roll Grinders.—These are another design of heavy machine for special operations in finishing mill rolls of large proportions.

Cutter and Tool Grinders.—These grinders are for general upkeep and handling of milling cutters, reamers, and similar tools; they are for both sizing and maintenance purposes. Other machines include drill grinders, lathe and planer tool grinders, and others.

The sketches and table, Fig. 1, refer to commercial grinding on cylindrical and allied work where average conditions of production finish, volume of work, and other factors obtain. Rates of operation quoted may be exceeded in high-production plants.

Data on Wheels

Whatever the form of machine considered, all use abrasive wheels in some type or other. The selection of such wheels is all-important. Slight variation in grain or grade of a wheel may affect the character of the work to a remarkable extent. Data pertaining to abrasives and wheels are of first importance in dealing with the subject of grinding.

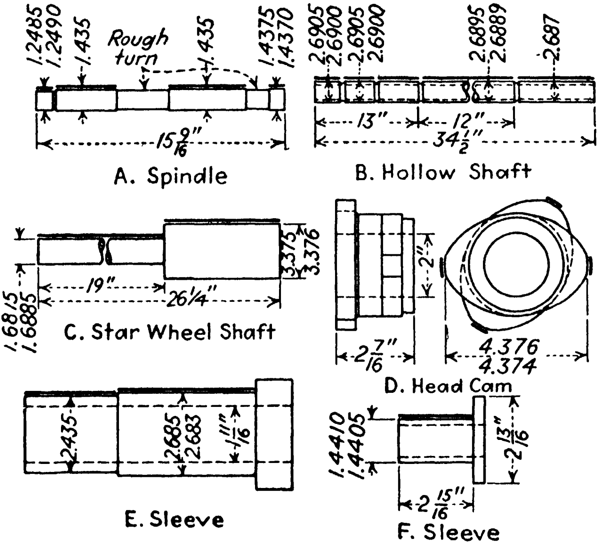


FIG. 1.—Examples of Commercial Grinding

THE COMMERCIAL ABRASIVES

Emery, corundum, Carborundum, Crystolon, Alundum, and Aloxite are the ordinary commercial abrasive materials. They vary in hardness, though it does not follow that the hardest grit is the best for cutting purposes; the shape and form of fracture of the particles must also be taken into consideration. We may imagine a wheel made up from diamonds, the hardest substance in nature, whose individual kernels were of spherical form; it is quite obvious that it would be of little service as a cutting agent; on the other hand, if these kernels were crystalline or conchoidal in form it would probably be the ideal grinding wheel.

Emery is a form of corundum found with a variable percentage of impurity; it is of a tough consistency and breaks with a conchoidal fracture.

Corundum is an oxide of aluminum of a somewhat variable purity, according to the neighborhood in which it is mined; its fracture is conchoidal and generally crystalline.

Carborundum and Crystolon abrasives are of silicide of carbon, which is a product of the electric furnace; it breaks with a sharp crystalline fracture.

TABLE OF PRODUCTION GRINDING OF CAN-MACHINE PARTS GROUND ON CINCINNATI 10- BY 36-INCH PLAIN HYDRAULIC MACHINE

Name of Part	Operation	Production	Material	Stock Removed, in Inches	No. of Cuts	Finish
A. Spindle	See sketch	10 per hr.	Low-carbon steel	0.015	1	Commercial
B. Hollow shaft	Grind all over	40 min. each	Shelby tubing	0 020 on account of spring in tubing		Commercial.
C. Star-wheel shaft	Grind all over	40 min per piece	Low-carbon steel	0.015	1	Commercial
D. Head cam	Grind working points	40 per hr.	Low-carbon steel	0.062	1 plunge cut	Commercial
E. Sleeve	Grind two diameters	6 per hr	Cast iron, ground on arbor	0.015	1	Commercial
F. Sleeve	Grind barrel	30 per hr	Low-carbon steel	0.015	1	Commercial

Alundum and Aloxite are also manufactured products, being fused oxide of aluminum. They are of uniform quality, of about 98 per cent purity, breaking with a sharp, conchoidal crystalline fracture and having all the toughness of emery.

Numerous other trade-mark names have been adopted by other manufacturers, among them: Carbolite, Carbolon, Carbora, Carbosolite, Carbowalt, Corex, Dicarbo, Electrolon, Gresolite, and Sterbon.

Other trade-mark names are numerous and include: Abrasit, Adamite, Alowalt, Bathite, Borolon, Calcinite, Carbo-alumina, Combin, Corolox, Corowalt, Dessus, Diamantite, Durubit, Electrit, Jeddite, Lionite Oxaluma, Rebite, Rex, Rexite, and Sterlith.

Grit and Bond

A grinding wheel is made up of the "grit," or cutting material, and the bond. The cutting efficiency of a wheel depends largely on the grit; the guide of hardness depends principally on the bonding material used. The efficiency in grinding a given metal is dependent largely upon the "temper," or resistance to fracture and, as noted before, upon the character of fracture of the grit or cutting grains of the wheel.

The function of the bond is not only to hold the cutting particles of the wheel together and to give the wheel the proper factor of safety at the speed it is to be run, but it must also be possible to vary its tensile strength to fit the work it is called upon to do. We often hear the operator say that the wheel is too hard or too soft. He means that the bond retains the cutting teeth so long that they become dulled, and this wheel is inefficient; or, in the case of a soft wheel, the bond has not been strong enough to hold the cutting teeth and they are pulled out of the wheel before they have done the work expected.

The bond to be used for a given operation depends on the wheel and work speeds, area of wheel in contact with the work, vibration in wheel spindle or work, shape and weight of work, and many other like variables. Wheels are bonded by what are known as the vitrified, silicate, shellac (elastic), Bakelite, and rubber processes. No one bond makes the best wheel for all purposes; each one has its field.

The vitrified bond is made of fused clays, is unchanged by heat or cold, and can be made in a greater range of hardness than any other bond. It does not completely fill the voids between the grains, and, therefore, a wheel bonded in this way having more clearance than any other is adaptable for all kinds of grinding except where the wheel is not thick enough to withstand side pressure. This bond has no elasticity.

The silicate bond is composed of clays fluxed by silicate of soda at low temperatures. It is not so stable as the vitrified bond as regards dampness, gives less clearance between grains, and has a range of hardness below that of the vitrified in the harder grades. This bond has no elasticity and will not make a safe wheel of extreme thinness.

The shellac bond is composed of shellac and other gums. It completely fills the voids of the wheel, has a limited range of grades, has a high tensile strength and elasticity and can be used for the making of very thin wheels. The rubber bond has the general characteristics of the shellac, but its grades of hardness cannot be varied to the same extent, and its uses are limited.

Bakelite snagging wheels, operating at 9,500 surface feet per minute, are being very successfully used for the high-speed snagging of steel and malleable castings and for billet and ingot grinding. Bakelite saw-gumming and cutting-off wheels are also finding large fields of usefulness.

Grain and Grade

Grinding wheels are made in various combinations of coarseness and hardness to meet the variety of conditions under which they are used. The cutting material is crushed and graded from coarse to fine in many sizes designated by number. By No. 20 grain is meant a size that will pass through a grading sieve having 20 meshes to the linear inch.

The term "grade" refers to the degree of hardness of the wheel or the resistance of the cutting particles under grinding pressure. A wheel from which the cutting particles are easily broken, causing it to wear rapidly, is called "soft," while one which retains its particles long is called "hard."

Wheel Markings

There was formerly standard system of marking grinding wheels to show their composition. Each manufacturer used a system of his own to describe the five important characteristics. These are (1) type of abrasive; (2) size of abrasive grain or degree of coarseness; (3) grade of hardness or strength of bond; (4) structure or distribution of abrasive grains; (5) kind of bond. (See pages 1419 to 1423*a* for new data.)

1. **Type of Abrasive.**—This is usually designated by the complete trade name of the kind of abrasive used (see The Commercial Abrasives for the more important names). This is not always necessary, however, as the introduction of the symbol "38," for instance, indicates the use of Norton No. 38 Alundum, and other characteristic symbols are also frequently used.

2. **Size of Abrasive Grain.**—The method of indicating the grain size or "coarseness" is more nearly universal than that for describing any other characteristic of the wheel. This is usually designated by a number indicating the approximate number of meshes per linear inch of a screen through which the abrasive grains will pass. Thus, the symbol "46" indicates that the wheel contains abrasive grains which would pass through a screen

GRAIN SIZES (NORTON STANDARDS)

Very Coarse	Coarse	Medium	Fine	Very Fine	Flour Sizes
4	12	30	70	150	280
6	14	36	80	180	320
8	16	46	90	220	400
10	20	60	100	240	500
..	24	..	120	...	600

having 46 meshes per linear inch. The higher numbers indicate finer grain size.

3. **Grade of Hardness or Strength of Bond.**—Most manufacturers use a letter following the grain symbol to designate the grade of the wheel. Unfortunately, however, these letters and their relation to each other do not always mean the same thing. In the Carborundum Company's scale of grades, the letters at the beginning of the alphabet indicate the hardest grades, and those at the end of the alphabet indicate the softest. Norton Company and most of the others use the alphabet scale in the reverse order, while a few manufacturers use special code arrangements of the letters.

For rubber, Bakelite, and shellac bonded wheels the grade is sometimes designated by letters, sometimes by numbers. Norton Company formerly used numbers but now uses letters to unify the system with that used for vitrified and silicate bonded wheels. The Carborundum Company uses numbers from 1 to 8, No. 1 being the hardest and No. 8 the softest, but many others use the number system in the reverse order.

On page 485 are shown the comparative gradings of the leading grinding-wheel manufacturers issued by Carborundum Company. The American Emery Wheel Works has a new listing, on page 486, with suggestions as to uses.

4. **Structure or Grain Spacing.**—Norton Company is introducing a symbol indicating the structure of the wheel or the distribution of the abrasive grains, Numbers are used following the letter which indicates the grade. A low number indicates a dense structure or a wheel with close spacing of grains, while a higher number indicates a more open structure or one with wider grain spacing. Thus a 46-M3 would be more dense than a 46-M8.

5. **Kind of Bond.**—This is frequently designated by a complete word describing the kind of bond used such as "vitrified," "silicate," "shellac," "rubber," "Bakelite," etc. Some manufacturers use symbols, numbers, or letters to designate these general classes or certain modifications thereof.

Storage

Extreme care should be exercised in the storage of wheels. Suitable racks or bins should be provided to accommodate the various types of wheels carried in stock.

Most straight and tapered wheels are best supported on edge in racks.

Thin rubber, shellac, and other organic bonded wheels should be laid flat on a plane surface to prevent warpage.

Cylinder wheels and large cup wheels should be stacked on the flat sides with corrugated paper or other cushioning material between them.

Small cup and other shape wheels and small internal grinding wheels may be stored in boxes, bins, or drawers.

Very large wheels can well be stored in original containers.

Inspection

Immediately upon receipt, all wheels should be closely inspected to make sure that they have not been injured in transit or otherwise. As an added precaution, wheels should be tapped gently (while suspended) with a light implement, such as the handle of a screw driver for light wheels or a wooden mallet for heavier wheels. If they sound cracked, they should not be used. Wheels must be dry and free from sawdust when applying the test, otherwise the sound will be deadened. It should also be noted that organic bonded wheels do not emit the same clear metallic ring as do vitrified and silicate wheels.

Mounting

Rigidity of Machine.—Grinding machines should be sufficiently heavy and rigid so as to minimize vibration. They should be securely mounted on substantial floors, benches, foundations, or other adequate structures.

GRADE MARKINGS OF WHEELS

	Carborundum	Norton	Abrasive	American	Safety	Sterling	Chicago	Vitrified	Courtland	Star	Hampden	Detroit	Carborundum Elastic	Abrasive Elastic	American Silicate	American Elastic	Detroit Elastic
Very hard		Z Y X W V U T	Z W U	Z W V U		6		G F3			Z Y X W V U T S	Z+4 Z+3 Z+2 Z+1					
Hard	D E F G+ G H+ H I+	S R Q P	T S R Q+ Q P+ P	T S R Q P	D E¾ E½ E¼ E N¾ N½ N¾ N O¾ O½ O¼ O I¾	Q¾ R½ S¼ T U¾ W½ Z¼ 4 J¾ K½ L¼	F E1 E D3	F2 F1 F E3 E2	R Q P	Z Y G1 G F2 F1 F	R Q P O N M L	Z Y X W V U T S R	1 2	7E 6E 5E	7 6 5 4½	7E 6E 5E 4½E	7 6 5
Medium	I J K	O N M	O+ O N	O N M	I½ I¼ I P¾ P½ P¼ P M¾ M½	M N¾ O½	D2 D C1	E1 E D3 D2 D1 D C3 C2	O N M	D2 D1 D C2 C	K J I H G	Q P O	3 4	3E 2½E 2E	4E 4 3½ 3	4E 3½E 3E	4 3 2½
Soft	L M N O P Q R S T	L K J I H	M+ M L+ L K+ K J	L K J I H	M¼ M A¾ A½ A¼ A H½ H C½ C	P¼ E F¾ G½ H¼ I	C B2 B1 B A1 A	C1 C B	L K J	B2 B1 B 2H W	F E	N M L K J I H G F	5 6 7 8 9	1¾E 1½E 1¾E 1E ¾E	2½ 2 1½ 1 ¾	2½E 2E 1½E 1E ¾E	2 1½
Very soft	U V W X Y Z	G F E	I H G	G								E D C B A	10 11	½E ¼E	½	½E	1

Diameter of Spindle.—No wheel of larger diameter or greater thickness than specified in the table on page 492 shall be used on any machine of given spindle diameter.

Grinding Wheel Markings

The American Emery Wheel Works mark their grinding wheels in the following manner and sequence:

1. Kind of abrasive (Aluminox, No. 29 Aluminox, No. 77 Aluminox, or Carbolite).
2. Size of grain or grit.
3. Grade, that is, grade of hardness indicated by bond strength. Usually soft grades on hard work and *vice versa*.
4. Abrasive content: *a*. high content, 0, 1, 2, 3; *b*, medium content, 4, 5, 6; low content, 7, 8, 9, 10, 11, 12.
5. Type of bond used: *a*. vitrified—V; silicate—S; shellac—E; resinoid—B.

An example of wheel marking is given below:

Abrasive	Grain Size	Grade	Abrasive Content	Bond
77	46	H	5	V

They suggest the following selection of abrasives for particular service:

Aluminum Oxide (Al_2O_3)			Silicon Carbide (SiC)
Aluminox (Very Tough)	No 29 Aluminox (Semi-Friable)	No. 77 Aluminox (Full-Friable)	Carbolite
Use on soft steels, alloy steel, annealed malleable iron, and wrought iron.	Use on mild steels, some hardened steels, and tough bronzes	Use on hardened steels, carbon steels, alloy steels, and high-speed steels	Use on cast iron, chilled iron, brass, bronze, aluminum, copper, tungsten carbide, stone, and nonmetallic substances
For snagging, rough heavy work, heavy-duty precision grinding, and general purpose.	For precision grinding, tool grinding, and internal grinding	For fine precision, tool-room work on tools, cutters, reamers, hobs, etc., and internal grinding	For snagging and precision grinding

Trade Names of Abrasives

The Clover Manufacturing Company, Norwalk, Conn., gives the following list of abrasives by trade names:

Trade Names	Abrasive Used
Abrasite	Aluminum oxide
Adalox	Aluminum oxide
Adamite	Aluminum oxide
Alabrase	Aluminum oxide
Alorix	Aluminum oxide
Al-Ox	Aluminum oxide
Aloxite	Aluminum oxide
Alundum	Aluminum oxide
Amunite	Silicon carbide
Ansandum	Aluminum oxide
Ansilicon	Silicon carbide
Ansolox	Aluminum oxide
A-O-66	Aluminum oxide
Armourite	Silicon carbide
Baco	Aluminum oxide
Blue-Stripe	Silicon carbide
Boxite	Aluminum oxide
Carbalox	Aluminum oxide
Carbicon	Silicon carbide
Carbonite	Silicon carbide
Carborix	Silicon carbide
Carborundum	Silicon carbide
Crystolon	Silicon carbide
Crystox	Silicon carbide
Durite	Silicon carbide
Durundum	Aluminum oxide
Electric-Abrasive	Aluminum oxide
Garalun	Aluminum oxide
Herculundum	Silicon carbide
Jewelite	Silicon carbide
Jewelox	Aluminum oxide
Luminox	Aluminum oxide
Lumnite	Aluminum oxide
Metalite	Aluminum oxide
Production	Aluminum oxide
Sil-Carb	Silicon carbide
Three-M-ite	Aluminum oxide
Tri-M-ite	Silicon carbide
Usalox	Aluminum oxide
Wausite	Aluminum oxide
Yellow-Stripe	Aluminum oxide

Selecting the Best Abrasives

Choosing the best type of abrasive is not always easy. Both the silicon carbide and aluminum oxide abrasives have their own fields, and there are also places where selection is a matter of personal opinion. The characteristics of the two types vary but not so widely as some imagine.

Silicon carbide is very hard but does not resist breakage as does the aluminum oxide. It breaks into particles that are angular in form and cut well. This, in the opinion of most grinders, makes it superior for use on very hard materials, such as cemented carbide tools, stone, and ceramic materials. Metals and other materials that are of low tensile strength are best ground with this comparatively fragile abrasive. Fracture of the cutting particles is necessary to provide new cutting points without great wheel wear, especially when cutting low-resistance materials.

Aluminum-oxide abrasives are not quite so hard as the silicon carbide, but are tougher, and the grains are not so easily broken. This makes them better adapted for grinding most steels because of their greater resistance to the impact of striking the steel surface. The silicon carbide grains break too easily, which means too rapid wheel wear, for use on steel.

This may be summed up in a general rule to use silicon carbide abrasives for materials of low tensile strength, regardless of their hardness, and to use aluminum oxide for materials of high tensile strength, such as steel. A list of materials suggested for grinding with the two types of wheels are:

SILICON CARBIDE	ALUMINUM OXIDE
Gray and chilled iron	Carbon steels
Brass and soft bronze	Alloy steels
Aluminum and copper	High speed steels
Marble and other stone	Annealed malleable iron
Rubber and leather	Wrought iron
Very hard alloys	Rough and hard bronzes
Cemented carbides	

Vitrified bonding is used in perhaps 75 per cent of all wheels used. The vitreous bond practically becomes glass under heat, and this glass holds the abrasive grains together firmly, but with considerable porosity. This enables it to remove material at a high rate. Not being affected by acids, oils, water, or climate, and being uniform in hardness, it is a favorite for many grinding operations.

Silicate bonding is primarily silicate of soda, which does not hold the grains of abrasive so firmly as the vitrified bond. This bond makes what grinders call a "milder" wheel, used largely in the grinding of edge tools. It is important in this work that the heat generated must be kept at a minimum.

Both silicon carbide and aluminum oxide abrasives are made by the same concerns in both Canada and the United States. The makers alphabetically arranged, and the trade names of both types of abrasives are given herewith:

Company	Trade Names	
	Silicon Carbide	Aluminum Oxide
Carborundum Company	Carborundum	Aloxite
Exolon Company	Carbolon	Exolon
General Abrasive Company	Carbonite	Lionite
Monsanto Chemical Company	Federal	Federal
Norton Company	Crystolon	Alundum

In addition, the Abrasive Company (not General Abrasive) makes Barolon, an aluminum-oxide abrasive.

Dust-Exhaust Provision.—Hoods on machines used for dry grinding and other operations where dust is produced should have provision made for connection to an exhaust system.

The size of such connections should be in conformity with the following specified dimensions:

Diameter of Wheel, Inches	Minimum Diameter of Branch Pipe, Inches
6 or less in diameter	3
7 to 16 in diameter	4
17 to 24 in diameter	5
25 to 30 in diameter	6

A modification of the above requirements will be allowed in the case of narrow wheels used for light work where very little dust is generated and where a smaller pipe will satisfactorily remove it.

Note.—A "Safety Code for the Use, Care, and Protection of Grinding Wheels," containing complete information on this subject, may be obtained gratis from the American Standards Association, 29 West 39th Street, New York, N. Y., or from any grinding wheel manufacturer.

SPINDLE THREADS

Direction of Spindle Thread.—Ends of spindles shall be so threaded that the nuts on both ends will tend to tighten as the spindles revolve. Care should be taken in setting up machines that the spindles are mounted so that they will revolve in the proper direction, otherwise the nuts on the ends will loosen.

Note.—To remove the nuts, they should both be turned in the direction that the spindle revolves when the wheel is in operation.

Work-Rest Adjustment.—The work rest should be kept adjusted close to the wheel, with a maximum distance of $\frac{1}{8}$ inch, to prevent the work from being caught between the wheel and rest and should be securely clamped after each adjustment. This adjustment shall not be made while the wheel is in motion. The rest should be maintained in good condition.

Flanges.—Flanges shall be recessed at least $\frac{1}{16}$ inch on the side next to the wheel.

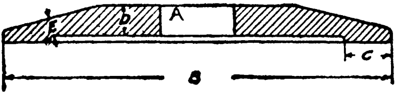
Fit.—The driving flange shall be keyed, screwed, shrunk, or pressed onto the spindle, and the bearing surface shall run true and at right angles with the spindle.

Surface Condition.—All surfaces of wheels, washers, and flanges in contact with each other should be free from foreign material.

Bushing.—The soft metal bushing shall not extend beyond the sides of the wheel. The hole in the wheel bushing should be 0.005 inch larger than standard size spindles. This permits the wheel to slide on the spindle without cramping and ensures a good fit not only on the spindle but against the inside flange, which is essential.

The hole in the wheel bushing should be 0.005 inch larger than standard-size spindles. This permits the wheel to slide on the spindle without cramping and ensures a good fit not only on the spindle but against the inside flange, which is essential.

Washers.—Washers or flange facings of compressible material shall be fitted between the wheel and its flanges. If blotting paper is used, it should not be thicker than 0.025 inch. If rubber or leather is used, it should not be thicker than 1 inch. If flanges with babbitt or lead facings are used, the thickness of the babbitt or lead should not exceed ⅛ inch. The diameter of the washers shall not be smaller than the diameter of the flanges. Fig. 2.



STANDARD DIMENSIONS OF PROTECTION FLANGES
(All Dimensions in Inches)

A Diameter of Wheel	*B* Minimum Outside Diameter of Flanges	*C* Radial Width of Bearing Surface		*D* Minimum Thickness of Flange at Bore	*E* Minimum Thickness of Flange at Edge of Recess
		Minimum	Maximum		
1	3/8	1/16	1/8	1/16	1/16
2	3/4	1/8	3/16	1/8	3/32
3	1	1/8	1/4	3/16	3/32
4	1 1/4	3/16	3/8	3/16	1/8
5	1 1/2	3/16	3/8	1/4	1/8
6	2	1/4	1/2	3/8	3/16
8	3	1/4	1/2	3/8	3/16
10	3 1/2	5/16	5/8	3/8	1/4
12	4	5/16	5/8	1/2	5/16
14	4 1/2	3/8	3/4	1/2	5/16
16	5 1/2	1/2	1	1/2	5/16
18	6	1/2	1	5/8	3/8
20	7	5/8	1 1/4	5/8	3/8
22	7 1/2	5/8	1 1/4	5/8	7/16
24	8	3/4	1 1/4	5/8	7/16
26	8 1/2	3/4	1 1/4	5/8	1/2
28	10	7/8	1 1/2	3/4	1/2
30	10	7/8	1 1/2	3/4	5/8
36	12	1	2	7/8	3/4

Tapered protection flanges shall always be used with tapered wheels having the same degree of taper, which should be at least ¾ inch per foot for each flange.

Tightening of Nut.—When tightening spindle-end nuts, care should be taken to tighten them only enough to hold the wheel firmly; otherwise, the clamping strain is liable to damage the wheel or associated parts.

Guards for Abrasive Wheels.—The safety code prescribes guards for abrasive wheels as shown in Fig. 3. The diagrams give the amount and the position of the openings for grinding machines of different types.

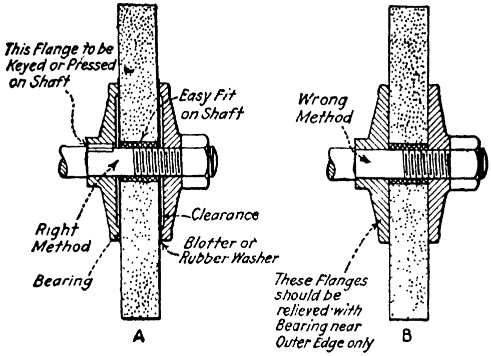

This Flange to be Keyed or Pressed on Shaft
Easy Fit on Shaft
Wrong Method
Clearance
Right Method
Blotter or Rubber Washer
Bearing
These Flanges should be relieved with Bearing near Outer Edge only
A
B

FIG. 2.—Right and Wrong Way to Mount Wheels

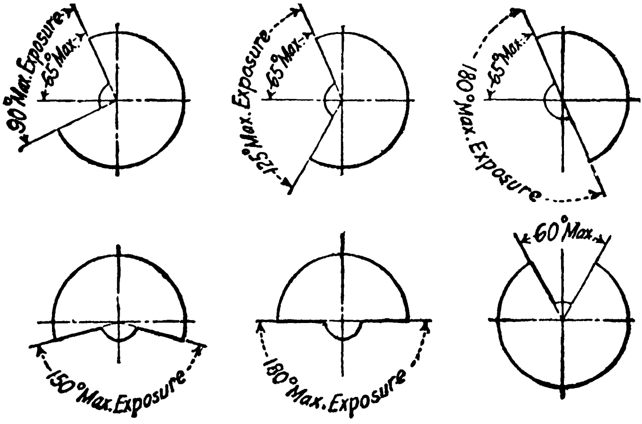


FIG. 3.—Wheel Guards

Diamond Grinding Wheels.—Diamond are rated by the "diamond concentration" which refers to the relative quantity of diamond of a given size, in a unit volume of the active portion of the wheel. One hundred concentration is the maximum to secure greatest cutting capacity with economy. Lower concentration indicates diamond particles spaced farther apart.

MINIMUM DIAMETERS OF SPINDLES FOR WHEELS OF VARIOUS DIAMETERS AND THICKNESSES OPERATING AT SPEEDS UP TO 7,000 PERIPHERAL FEET PER MINUTE

Diameter of Wheel, Inches	Thickness of Wheel, Inches																		
	¼	⅜	½	⅝	¾	1	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	4	4½	5
	Diameter of Spindle, Inches																		
6	½	½	½	½	½	½	⅝	⅝	¾	¾	¾	¾	¾	¾	¾	¾	1	1	1
7	½	½	½	½	⅝	⅝	⅝	¾	¾	¾	¾	¾	¾	1	1	1	1	1	1
8	⅝	⅝	⅝	⅝	⅝	⅝	¾	¾	¾	1	1	1	1	1	1	1	1¼	1¼	1¼
9	⅝	⅝	⅝	⅝	¾	¾	¾	¾	1	1	1	1	1	1¼	1¼	1¼	1¼	1¼	1¼
10	¾	¾	¾	¾	¾	¾	¾	¾	1	1	1	1¼	1¼	1¼	1¼	1¼	1¼	1½	1½
12	¾	¾	¾	¾	¾	1	1	1	1	1	1	1¼	1¼	1¼	1¼	1¼	1½	1½	1½
14	⅞	⅞	⅞	⅞	1	1	1¼	1¼	1¼	1¼	1¼	1¼	1¼	1½	1½	1½	1½	1½	1½
16	..	..	..	..	1¼	1¼	1¼	1¼	1¼	1¼	1½	1½	1½	1½	1½	1¾	1¾	1¾	1¾
18	..	..	..	..	1¼	1¼	1¼	1½	1½	1½	1½	1½	1½	1½	1¾	1¾	1¾	1⅞	1⅞
20	..	..	..	..	..	1½	1½	1½	1½	1½	1½	1½	1¾	1¾	1¾	1⅞	1⅞	1⅞	1⅞
24	..	..	..	..	..	1½	1½	1½	1¾	1¾	1¾	1¾	1¾	1¾	2	2	2	2	2
26	..	..	..	..	..	..	1½	1½	1¾	1¾	1¾	1¾	2	2	2	2	2¼	2¼	2¼
30	..	..	..	..	..	..	..	1¾	1¾	2	2	2	2	2	2¼	2¼	2½	2½	2½
36	..	..	..	..	..	..	..		2	2¼	2¼	2¼	2½	2½	2½	2¾	2¾	3	3

NOTE: For speeds exceeding 7,000 peripheral feet per minute, the spindle sizes shown in the above table are usually not adequate. Inasmuch as the proper spindle size is dependent upon many factors, such as general design of the machine, type of bearings, quality of materials and workmanship, a simple table is not practicable. Wheels larger than specified by the machine manufacturer should not be used on any given machine.

DRESSING AND TRUING

The terms "dressing" and "truing" are frequently confused or carelessly interchanged. Actually, there is a definite distinction. The term dressing should be used to describe the reconditioning of the grinding surface of a wheel which has lost some of its cutting ability because of glazing or loading. Theoretically, this operation is unnecessary if the wheel is of the correct specifications for the work. The term truing should be used to describe the operation of restoring the grinding surface of the wheel to its correct geometrical shape—cylindrical, conical, plane, or formed, as the case might be. For precision grinding of all kinds truing is necessary at intervals in order to insure accuracy of results.

A wheel could be satisfactorily dressed but still require truing. The truing operation, however, if correctly done with the proper tool will perform the function of dressing at the same time. From this it will be understood then that ordinary dressing of wheels used for precision grinding is not sufficient but may be satisfactory on snagging and other offhand operations where accuracy is not of great importance.

The most common type of offhand dressing tool consists essentially of a number of circular metal cutters mounted on a spindle in a suitable holder. These cutters are of numerous shapes and styles to suit various classes of work and are known by various names, such as "Huntington," "Ross," etc. The Metcalf dresser consists of an abrasive wheel mounted on a spindle with a handle at each end.

For truing wheels on precision machines a diamond tool or some well-built truing device which employs abrasive wheels should be used. Huntington dressers or other types using metal discs as the cutting medium are not suitable. Truing devices must also be firmly supported. Offhand application of the tool should never be permitted.

Diamonds should be the hardest rough stones procurable, and the larger stones are cheaper in the end. A large stone allows of a more secure hold in its setting, and so the danger of losing it is reduced. The diamond tool should always be held by mechanical means when it is in use, except in cases which are unavoidable.

Diamonds for Grinding Wheels

About 90 per cent of all industrial diamonds are used in grinding wheel dressers. Large stones are recommended for heavy work, smaller for lighter work, depending on conditions. Recommendations for Landis and Norton nibs are shown in the table at top of page 494.

Light truing cuts are generally preferable. When used, coolant should cover the full face of the wheel. Machines should be level and steady. The dresser should move slowly and uniformly across entire face. Turn holder often, from one-fourth to one-third turn. Reset the diamond before it is worn level with holder. Avoid shattering the diamond by impact at the edges of the wheel.

	Carats	
Wheel diameter under 8 inches	0.300 to 0.750	Depending on conditions, type of wheel, grain, etc.
Wheel diameter under 12 inches	1.000 to 1.250	
Wheel diameter under 24 inches	1.500 to 3.000	
Wheel diameter over 24 inches	3.500 to 10.000	

Dresser diamonds are properly tough stones with a maximum number of sharp points, mounted in their natural form, but in some light-duty cases they can be shaped to a point or to a chisel edge. Craft's Permaset contains a long slim diamond set in an extended nib. This allows long service without resetting. The diamond is used until entirely worn away. This type of dresser eliminates resetting. Carat weights recommended for Permaset follow:

Wheel Diameter and Face, in Inches	Average Carat Weight	Wheel Diameter and Face, in Inches	Average Carat Weight
6 × ½	0 300	18 × 2	1.750
8 × 1	0 600	20 × 2	2 000
10 × 1	0.750	24 × 2	2.250
12 × 1	1.000	24 × 3	2 500
14 × 1½	1.250	24 × 4	3.000
18 × 1½	1.500	26 × 4	3.500

Setting the Diamonds

Diamonds may be obtained ready fixed in suitable holders, or the rough stones may be bought and set by any competent toolmaker.

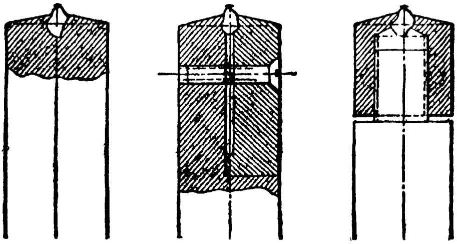


FIG. 4 FIG. 5 FIG. 6

FIG. 4–6.—Methods of Setting Diamonds

The illustrations show various methods by which they may be held securely, and require but little explanation. First, Fig. 4 is the method most commonly used, the diamond being either peened or brazed in position. One disadvantage of this method is that the diamond is apt to break with a chance blow of the peening chisel, or the heat from brazing will sometimes cause fractures; neither is it so easily reset when its point becomes dulled as are the other settings shown. Figure 5 requires no explanation, except that it is advisable to pack the diamond with shredded asbestos fiber to act as a cushion; this method allows of quick resetting. Figure 6 consists of a small steel cap tapped out to fit the stock as shown. Enough shredded asbestos fiber is inserted between the diamond and stock to hold it firmly in position. This method also allows of quick and safe resetting.

Use of Coolant or Lubricant

In grinding metals and many nonmetallic substances, it is essential to use a coolant to dissipate the heat generated by the abrading action and friction. It is particularly true in precision grinding that an equable, moderate temperature be maintained in the work to obviate distortion and to make accurate size taking possible during or immediately following the grinding operation.

Although clear water can be used for this purpose, it causes rusting of the machine and work and lacks many desirable characteristics of other cooling media. Addition of soda or alkali in various forms to the water overcomes the trouble from rusting. Solutions containing soapy emulsions or soluble oil compounds are valuable as rust preventives and their lubricating quality tends to reduce the heat generated and to improve the finish produced by the grinding wheel. Kerosene or other light oil solutions are used for aluminum and its alloys, and these permit settling of the light chips and aid effective grinding action.

Use of a grinding fluid tends to keep the wheel face from loading or filling with particles of the material being ground, thus improving its cutting action. It also settles the abrasive dust, preventing contamination of exposed bearing surfaces and adding to the hygienic conditions of the workman.

The coolant should be applied in ample volume directly to the grinding point. Applying the grinding fluid remotely or using too little reduces its effectiveness and may even cause distortion or surface defects such as checking.

CLEAN COOLANT CUTS COSTS

Coolant thoroughly cleaned by centrifugal separator produces better work and saves grinding-wheel cost by making wheels last up to 20 per cent longer, which also saves on wear of the diamonds used in truing. With continuous cleaning much less coolant is needed, and it is not necessary to throw away old coolant and mix a new batch, as no sludge is permitted to form.

The amount of coolant is also important. One expert advises 2 gallons per minute for each actual horse-power used. Brown and Sharpe recommends a solution of ½ pound sal soda per gallon of water. Soluble oils are also satisfactory. For continuous work the tank should hold 2 to 2½ times the total flow per minute.

General Suggestions

Competent men shall be assigned to the mounting, care, and inspection of grinding wheels and machines.

After mounting a new wheel, care should be taken to see that the hood is properly replaced.

All new wheels shall be run at full operating speed for at least 1 minute before applying work, during which time the operator shall stand at one side.

Work should not be forced against a cold wheel but applied gradually, giving the wheel an opportunity to warm and thereby minimize the chance of breakage. This applies to starting work in the morning in cold rooms and to new wheels which have been stored in a cold place.

Grinding on the flat sides of straight wheels is often hazardous and should not be allowed on such operations when the sides of the wheels are appreciably worn thereby or when any considerable or sudden pressure is brought to bear against the sides.

Care should be exercised in lubrication so that the spindle will not become sufficiently heated to damage the wheel.

FACTORS AFFECTING GRINDING-WHEEL SELECTION

The selection of a grinding wheel for a given piece of work is not a guess—neither is it calculable by mathematics. Grinding plays an important part in our modern manufacturing processes, and an understanding of the factors involved in selecting a grinding wheel for a certain job is extremely helpful to the shop superintendent, methods engineer, foreman or workman. The following general factors govern grinding-wheel selection:

Given conditions:

1. Material to be ground.
2. Amount of material to be removed and finish desired.
3. Arc of contact.
4. Type of grinding machine.

Influential variable factors:

1. Wheel speed.
2. Work speed (or pressure if hand grinding).
3. Condition of machine.
4. Skill of the workman.

1. Material to Be Ground.—The composite effect of several physical properties of a material to be ground largely governs the selection of the type of abrasive to be used. For materials that are neither very brittle nor very easily penetrated, crystalline aluminum oxide wheels have been found most suitable. Most materials for which this abrasive is better adapted are comparatively high in tensile strength. Therefore, beginning with the hardest and toughest of alloy steels, down to and including the tougher grades of bronze, *aluminum oxide* grinding wheels should be used.

For materials that are very easily penetrated, such as leather, and for those which are hard but very brittle, such as stone, silicon carbide wheels are more suitable. Cast and chilled irons offer moderate resistance to penetration and are sufficiently brittle compared with hardened steel to make silicon carbide the more effective abrasive for them. Also other materials of low tensile strength, such as soft brasses and bronzes, aluminum, and copper, are more efficiently ground with *silicon carbide* grinding wheels.

2. **Amount of Material to be Removed.**—The amount of material to be removed by the grinding wheel and the finish desired influence the selection of the grit size, because, where comparatively large amounts of material have to be removed by grinding, the coarser grain combinations should be employed to facilitate the rapid removal of stock. This applies particularly to hand grinding operations like snagging castings, where finish is no consideration, but rapid cutting qualities are essential.

Finish is dependent to a considerable extent on grit size used, except on machine grinding operations, where proper truing and dressing facilities afford a means of obtaining fine finish without the sacrifice of production usually accompanying the use of fine grit wheels.

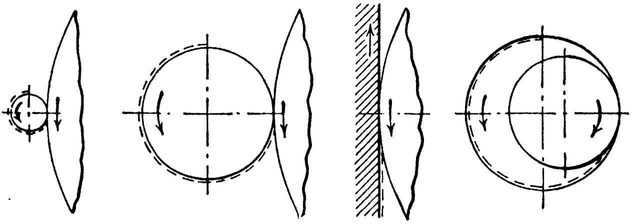


FIG. 7
Grinding Small Diameter

FIG. 8
Grinding Large Diameter

FIG. 9
Grinding Flat Surface

FIG. 10
Internal Grinding

FIGS. 7–10.—Contact of Grinding Wheel

3. **Arc of Contact.**—The arc of contact, or the area of contact, has a very important bearing on the grain and grade selection. By the "arc of contact" is meant the length of the arc (measured along the periphery of the wheel) that is in contact with the work being ground. The two extremes of the length of this arc are illustrated by Figs. 7 and 10. The difference in the length of the arc of contact in these two extremes is actually rather small, but the effect of this difference on the grinding wheel is great. In the first case, a medium-hard wheel is required, whereas only the softest grades will grind satisfactorily in the second case.

In the case of cup or cylinder wheels where the grinding is done on the rim, the arc of contact develops into an area of contact and the effect of a change from a small area to a large area is even more marked than with a straight wheel. The extremes here range from the grinding of steel balls, where practically "point contact" exists, to the grinding of broad, flat surfaces. To select a wheel suitable to the variations in the area of contact, grades F to Z (Norton) have to be employed.

The "arc of contact" and "area of contact" should not be confused with the "width of contact." By "width of contact" is meant the width of the wheel in contact with the work in the case of cylindrical grinding, or the width of the rim in the case of cup and cylinder wheels. Width of contact has practically no effect on the cutting action of a wheel, provided, of course, pressure per unit area remains constant and there is sufficient power in the drive. In other words, there should be no difference in the cutting action of a wheel 1 inch wide and another 4 inches wide, or a cup with 1-inch rim or one with a 2-inch rim, provided the pressure per unit area remains the same.

4. Type of Grinding Machine.—In the majority of cases when a grinding wheel has to be selected for a given job, the grinding machine is already available and becomes an important factor in grinding-wheel selection. Heavy, rigidly constructed machines take softer wheels than lighter, more flexible types. Some machines set up greater vibrations than others, thus calling for finer and harder wheels. The combination of speeds and feeds on some precision machines makes the use of different kinds of wheels necessary. Plane-surface grinding machines making use of the rim of a cup or cylinder wheel require much softer wheels than plane-surface machines using the periphery of a straight or disk wheel.

Influential Variable Factors

1. Wheel Speed.—Too slow a speed means waste of abrasive without getting much useful work in return, and an excessive speed may retard cutting and if carried too far might become dangerous. Run a grinding wheel at somewhere near the speed recommended by the maker, as he has found by years of experience that certain speeds work better than others. The grits and grades usually recommended for certain grinding operations are based on the assumption that approximately the recommended speeds will be employed. If, for some reason, these speeds cannot be used, then the grade at least must be changed to suit this condition.

RECOMMENDED WHEEL SPEEDS

	SURFACE FEET PER MINUTE
Cylindrical grinding	5,500 to 6,500
Internal grinding	2,000 to 6,000
Snagging, offhand grinding (vitrified)	5,000 to 6,000
Snagging, rubber, and Bakelite wheels	7,500 to 9,500
Surface grinding	4,000 to 5,000
Machine-knife grinding	3,500 to 4,000
Hemming cylinders	2,100 to 5,000*
Wet-tool grinding	5,000 to 6,000
Cutlery wheels	4,000 to 5,000
Rubber, shellac, and Bakelite cutting-off wheels	9,000 to 16,000

* The higher speed is recommended only where suitable bearings are employed.

2. **Work Speed.**—In machine grinding, speed of work exerts a very pronounced effect on the grinding wheel and hence has to be allowed for in grinding-wheel selection. In general, fast work speed, whether the operation be cylindrical, surface, or internal grinding, tends to wear the wheel out faster than slower work speed. This is not necessarily a drawback to good grinding practice, but it must be understood to be properly controlled.

Wheel wear is dependent on the ratio of the surface wheel speed to the surface work speed. The higher the ratio the less work the wheel is required to do in a given amount of time, hence the wheel naturally wears at a .slower rate. If the ratio is decreased by increasing the work speed, the wheel will be required to do more work in a given time and will wear faster.

In general, the longer the arc of contact in precision grinding operations, the faster should be the speed of the work, in order to have the wheel cut properly.

In hand grinding, the rate at which the work is forced against the wheel or the method of applying the work exerts an influence on grade selection. The harder the grinding wheel is forced, the harder should be the wheel if abrasive economy is to be expected.

3. **Condition of the Grinding Machine.**—A grinding wheel is a refined tool (as is a milling cutter) and cannot work to good advantage on a machine in poor repair or not properly set up. In such cases allowances must be made at least in the selection of the grade of the wheel. Spindles loose in their bearings necessitate the use of very much harder wheels than would be used under normal conditions. Insecure or shaky foundations cause no end of trouble in grinding, because hard grades have to be employed to overcome the tendency of the wheel to wear rapidly, and thus cutting qualities are sacrificed.

4. **Personal Factor or Skill of the Workman.**—The workman's knowledge of the tool he is using and of its limitations is an important factor in the use of grinding wheels, just as much as in the use of other refined tools. It has been found that on hand grinding it is possible for grinding costs to vary 100 per cent on the same work and with the same kind of a machine in the same factory, owing to the difference in the men's methods of applying the work to the wheel. Even in machine grinding, the operator can vary the results and grinding costs by his methods of handling the machine.

1. Factors affecting the selection of the abrasive:

A. Physical properties of the material to be ground..............	Use aluminous abrasive grinding wheels for materials of high tensile strength	Carbon steels Alloy steels High-speed steels Annealed malleable iron Wrought iron Tough bronzes Tungsten, etc.
	Use silicon carbide grinding wheels for materials of low tensile strength	Gray iron Chilled iron Brass and bronze Aluminum and copper Marble Granite Pearl Rubber Leather, etc.

2. Factors affecting the selection of the grit:

A. Amount of material to be removed	Use coarse wheels for fast removal of stock
B. Finish desired..................	Use fine grain for fine finish
C. Physical properties of material to be ground.....................	Use coarse grain for ductile materials and finer grain for hard, dense or brittle materials

3. Factors affecting the selection of the grade (degree of hardness):

A. Physical properties of the material to be ground.............	Use hard wheels on soft materials and *vice versa*
B. Arc of contact....	The shorter the contact, the harder the wheel should be
C. Wheel speed and work speed.....	The higher the ratio of wheel speed to work speed the softer the grade should be and *vice versa*
D. Condition of grinding machine...	Machines in poor condition require harder wheels than machines in good condition
E. Skill of operator................	Skilful operator can use softer wheels than unskilled man—softer wheels mean more economical production Piece-work grinding usually calls for harder wheels than day work

4. Factors affecting the selection of the process:

A. Dimensions of wheel...........	Wheels subjected to bending strains should be made by elastic or rubber process Extremely thin abrasive saws must be made by the elastic or rubber process Wheels over 36-inch diameter are usually made by the silicate process
B. Rate of cutting................	Use vitrified wheels for most rapid cutting at speeds under 6,500 s.f.p.m.; rubber wheels at higher speed.
C. Finish desired.................	Use elastic or rubber wheels for highest finish, where rapid production is not a factor Use silicate wheels to replace sandstones on cutlery, etc.

Grinding-Wheel Recommendations

A grain and grade list such as this reaches its maximum usefulness only after its purpose is familiar to the user. The table beginning on page 505 lists common grinding operations. The wheel speeds on page 498 should be used with the wheels of a size commonly used for the work and the machines in good operating condition.

Grinding wheels are sometimes made of a combination of grains and are designated as, for example, 24 combination. A combination wheel with a mixture of fine, coarse, and medium grain sizes has a different cutting action from a straight-grained wheel and is desirable for certain operations, particularly cylindrical grinding. Such wheels are designated by C, as 24C-K. (See page 505.)

Speed Tables, Rules for Surface Speeds, Etc.

The table on page 503 gives the number of revolutions per minute at which grinding wheels of diameters ranging from 1 to 60 inches must be operated to secure peripheral velocities of 4,000, 5,000, 5,500, and 6,000 feet per minute. Ordinarily a speed of 5,000 feet per minute is employed, though sometimes the speed is somewhat lower or higher for certain cases.

The exact speed at which any specified wheel should be run depends upon several conditions, such as the type of machine, character of work and wheel, quality of finish desired, and various other factors referred to at other places in this book. Wheels are ordinarily run in practice from about 4,000 to 6,000 feet per minute, though in some cases a speed as high as 7,500 feet has been employed. An average speed recommended by most wheelmakers is 5,000 feet. To allow an ample margin of safety it is recommended that wheel speeds should not exceed 6,000 feet per minute.

Standard Types of Grinding Wheels

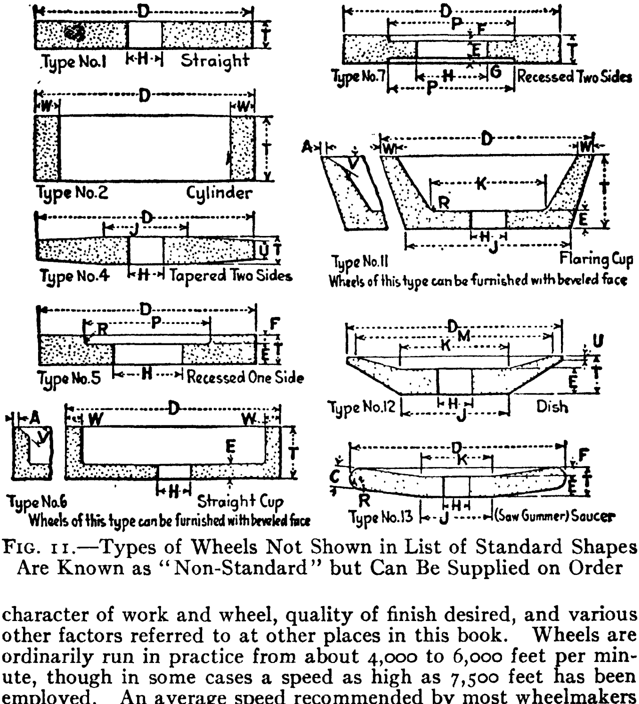

Type No.1 Straight
Type No.2 Cylinder
Type No.4 Tapered Two Sides
Type No.5 Recessed One Side
Type No.6 Straight Cup
Wheels of this type can be furnished with beveled face
Type No.7 Recessed Two Sides
Type No.11 Flaring Cup
Wheels of this type can be furnished with beveled face
Type No.12 Dish
Type No.13 (Saw Gummer) Saucer
D
H
T
W
J
U
R
P
F
E
A
V
G
K
M
C

FIG. 11.—Types of Wheels Not Shown in List of Standard Shapes Are Known as "Non-Standard" but Can Be Supplied on Order

Selecting Grinding Wheels

Selection of the best grinding wheel for each type of work is not a simple matter. Much depends on the machine, the operator, and the economical purchase of new wheels. Some consider the life of the wheel rather than the amount of work it produces. As with other tools, it is economy to secure the greatest possible amount of work in the shortest time. This obtains maximum efficiency from the men, the machines, and the plant. Although the grinding wheels recommended by Norton are still good general guides,

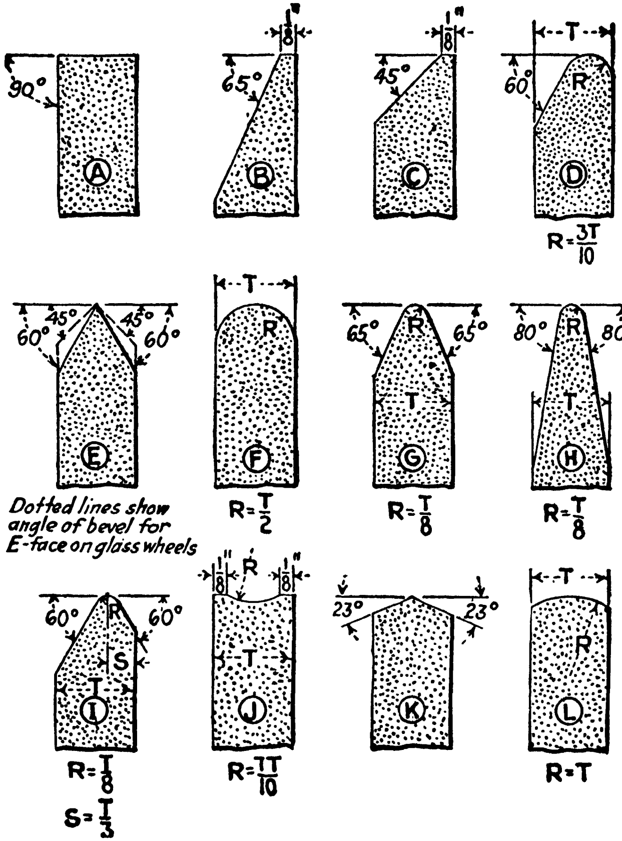


FIG. 12.—Standard Faces of Grinding Wheels

Abrasive wheel makers should be consulted when in doubt as to the performance of any grinding wheel. They publish very helpful charts and tables, which can also be found in standard handbooks. In general, however, the following recommendations can be safely followed:

Use silicon-carbide abrasives on low-tensile materials such as aluminum, brass, bronze, cast iron, and plastics.

Use aluminum oxide abrasives on high-tensile materials such as steel, malleable irons, tough bronzes, and other hard materials.

Use vitrified bonds for cast irons and steels, and shellac bonds for aluminum.

Wet Belt Grinding

REVOLUTIONS PER MINUTE FOR VARIOUS DIAMETERS OF GRINDING WHEELS TO GIVE PERIPHERAL SPEED IN FEET PER MINUTE AS INDICATED

Diameter of Wheel, Inches	Peripheral Speed in Feet per Minute											
	4,000	4.500	5,000	5.500	6,000	6.500	7,000	7.500	8,000	8,500	9,000	9.500
	Revolutions per Minute											
1	15,279	17,189	19,098	21,008	22,918	24,828	26,737	28,647	30,558	32,467	34,377	36,287
2	7,639	8,594	9,549	10,504	11,459	12,414	13,368	14,328	15,278	16,238	17,188	18,143
3	5,093	5,729	6,366	7,003	7,639	8,276	8,913	9,549	10,186	10,822	11,459	12,115
4	3,820	4,297	4,775	5,252	5,729	6,207	6,685	7,162	7,640	8,116	8,595	9,072
5	3,056	3,438	3,820	4,202	4,584	4,966	5,348	5,730	6,112	6,494	6,876	7,258
6	2,546	2,865	3,183	3,501	3,820	4,138	4,456	4,775	5,092	5,411	5,729	6,048
7	2,183	2,455	2,728	3,001	3,274	3,547	3,820	4,092	4,366	4,538	4,911	5,183
8	1,910	2,148	2,387	2,626	2,865	3,103	3,342	3,580	3,820	4,058	4,297	4,535
10	1,528	1,719	1,910	2,101	2,292	2,483	2,674	2,865	3,056	3,247	3,438	3,629
12	1,273	1,432	1,591	1,751	1,910	2,069	2,228	2,386	2,546	2,705	2,864	3,023
14	1,091	1,228	1,364	1,500	1,637	1,773	1,910	2,046	2,182	2,319	2,455	2,592
16	955	1,074	1,194	1,313	1,432	1,552	1,672	1,791	1,910	2,029	2,149	2,268
18	849	955	1,061	1,167	1,273	1,379	1,485	1,591	1,698	1,803	1,910	2,016
20	764	859	955	1,050	1,146	1,241	1,337	1,432	1,528	1,623	1,719	1,814
22	694	781	868	955	1,042	1,128	1,215	1,302	1,388	1,476	1,562	1,649

REVOLUTIONS PER MINUTE FOR VARIOUS DIAMETERS OF GRINDING WHEELS TO GIVE PERIPHERAL SPEED IN FEET PER MINUTE AS INDICATED—*Continued*

Diameter of Wheel, Inches	Peripheral Speed in Feet per Minute											
	4,000	4,500	5,000	5,500	6,000	6,500	7,000	7,500	8,000	8,500	9,000	9,500
	Revolutions per Minute											
24	637	716	796	875	955	1,034	1,115	1,194	1,274	1,353	1,433	1,512
26	588	661	734	808	881	955	1,028	1,101	1,176	1,248	1,322	1,395
28	546	614	682	750	818	887	955	1,023	1,092	1,159	1,228	1,296
30	509	573	637	700	764	828	891	955	1,018	1,082	1,146	1,210
32	477	537	597	656	716	776	836	895	954	1,014	1,074	1,134
34	449	505	562	618	674	730	786	843	898	955	1,011	1,067
36	424	477	530	583	637	690	742	795	848	902	954	1,007

NOTE: "Centrifugal force," which is the force that tends to rupture a given wheel when overspeeding, increases as the square of the velocity of that wheel. For example, the centrifugal force in a wheel running at 5,500 surface feet per minute is 49 per cent greater than in the same wheel running at 4,500 surface feet per minute, although the speed is actually only 22 per cent greater.

NORTON GRINDING-WHEEL RECOMMENDATIONS

Work—Material—Operation	Abrasive	Grain	Grade	Structure	Bond	Abrasive (Trade Mark)	Bonding Process
Aluminum:							
Cylindrical	37	30	J	8		Crystolon	Vitrified
Surfacing (cups or cylinders)	38	24	K	8	B	Alundum	Vitrified
Surfacing (straight wheels)	38	46	H	8	B	Alundum	Vitrified
Internal	37	46	K			Crystolon	Vitrified
Snagging (low speed)	37	24	O	6		Crystolon	Vitrified
Snagging (high speed)		30	N	4	T2	Alundum	Bakelite
Cutting-off		24	S	8	T2	Alundum	Bakelite
Armatures (laminations):							
Cylindrical		36	L	5	B	Alundum	Vitrified
Internal		36	J	5	B	Alundum	Vitrified
Ascoloy shafts, cylindrical	37	46	M	5		Crystolon	Vitrified
Axes (soft steel):							
Siding		36	T	5	B	Alundum	Vitrified
Edging (scribing)		20	R			Alundum	Vitrified
Edging (high speed)		30	Q	4	T2	Alundum	Bakelite
Axles (automobile):							
Centerless		46	M	5	B	Alundum	Vitrified
Cylindrical		46	L	5	B	Alundum	Vitrified
Axles (railway and automobile), cylindrical		46	L	5	B	Alundum	Vitrified
Ball bearings:							
Surfacing cups and cones—soft	38	46	G		S	Alundum	Silicate
Surfacing cups and cones—hard	38	80	F		S	Alundum	Silicate
Grind O.D. cups—rough and finish		80	M	6	B	Alundum	Vitrified
Grind outer race		80	R	6	R	Alundum	Rubber
Grind inner race		120	P	2	R	Alundum	Rubber
Internal grain bore		60	M	4	B	Alundum	Vitrified
Balls (hard—large), final finish	37	320F	X	9A		Crystolon	Vitrified
Balls (hard—small), final finish	37	XF	Z4	11		Crystolon	Vitrified
Billets (high-carbon and high-speed steels):							
Cleaning (high-speed swing frames)		14	Q	4	T2	Alundum	Bakelite
Cleaning (flexible shaft)		20	Q	5	B	Alundum	Vitrified
Billets (stainless and alloy steels):							
Cleaning (high-speed swing frames)		12	S	4	T3A	Alundum	Bakelite
Cleaning (flexible shaft)		20	R	7	B	Alundum	Vitrified
Bits (auger):							
Grinding throats		36	R		R	Alundum	Rubber
Fluting		70	R		R	Alundum	Rubber
Bolts (case-hardened steel):							
Cylindrical		60	L	5	B	Alundum	Vitrified
Centerless		60	N	5	B	Alundum	Vitrified
Brake shoes (chilled iron), snagging	37	20	S	5		Crystolon	Vitrified

Norton Grinding-Wheel Recommendations.—*Continued*

Work—Material—Operation	Abrasive	Grain	Grade	Structure	Bond	Abrasive (Trade Mark)	Bonding Process
Brass:							
Centerless	37	36	N	5		Crystolon	Vitrified
Cylindrical	37	36	K	5		Crystolon	Vitrified
Internal	37	36	J	6		Crystolon	Vitrified
Surfacing (cups and cylinders)	37	24	H	8		Cyrstolon	Vitrified
Snagging (high speed)	37	20	O	2	T2	Crystolon	Bakelite
Cutting-off		30	W	7	T3	Alundum	Bakelite
Broaches, sharpening	38	46	K	5	B	Alundum	Vitrified
Bronze (soft) use same wheels as for brass							
Bronze (hard):							
Centerless	37	50	K	5		Crystolon	Vitrified
Cylindrical		46	K	5	B	Alundum	Vitrified
Internal	38	60	J	5	B	Alundum	Vitrified
Snagging		20	Q	8	B	Alundum	Vitrified
Cutting-off		30	W	7	T3	Alundum	Bakelite
Bushings (hardened steel):							
Cylindrical		60	L	5	B	Alundum	Vitrified
Internal	38	60	K	5	B	Alundum	Vitrified
Centerless (rough)		[illegible]	M	5	B	Alundum	Vitrified
Centerless (finish)		120	N	0	R	Alundum	Rubber
Bushings (cast iron):							
Cylindrical	37	46	K	5		Crystolon	Vitrified
	38	46	J	5	B	Alundum	Vitrified
Internal	37	46	I	8		Crystolon	Vitrified
Cam rollers (hardened steel):							
Cylindrical	38	60	N	6	B	Alundum	Vitrified
Internal	38	60	L			Alundum	Vitrified
Cams (hardened steel):							
Rough and finish							
Hand machines		70	P	8	T2	Alundum	Bakelite
Automatic		70	O	8	T2	Alundum	Bakelite
Cams (cast alloy):							
Rough and finish (hand machines)		70	P	8	T2	Alundum	Bakelite
	37	60	Q	6	T2	Crystolon	Bakelite
Rough and finish (automatic machines)		70	O	8	T2	Alundum	Bakelite
	37	60	P	6	T2	Crystolon	Bakelite
Camshaft bearings, cylindrical		46	N	5	B	Alundum	Vitrified
Car wheels (chilled iron), cylindrical		16C	N			Alundum	Vitrified
Car wheels (steel), cylindrical		20	P	5	B	Alundum	Vitrified
Car wheels (manganese steel), cylindrical		16	Q	8	B	Alundum	Vitrified
Carbon (soft), cutting-off	37	16	R		R	Crystolon	Rubber
Carbon (hard-round-small):							
Centerless	37	36	N	5		Crystolon	Vitrified
Cutting-off	37	46	R	6	T2	Crystolon	Bakelite
Carbon (hard-round-large), cutting-off	37	46	R	6	T2	Crystolon	Bakelite
Card clothing:							
Pointing tips	35	100	S		R	Alundum	Rubber
Cylindrical		16	Q	5	B	Alundum	Vitrified

NORTON GRINDING-WHEEL RECOMMENDATIONS.—*Continued*

Work—Material—Operation	Abrasive	Grain	Grade	Structure	Bond	Abrasive (Trade Mark)	Bonding Process
Casein:							
Cutting-off	37	46	P	6	T2	Crystolon	Bakelite
Cylindrical	37	46	J	5		Crystolon	Vitrified
Cylindrical (form grinding)	37	100	M			Crystolon	Vitrified
Surfacing	37	36	H	6		Crystolon	Vitrified
Cast iron:							
Centerless	37	46	L	5		Crystolon	Vitrified
Cutting-off	37	36	R	8	T2	Crystolon	Bakelite
Cylindrical	37	36	J			Crystolon	Vitrified
Internal	37	46	J			Crystolon	Vitrified
Surfacing (cups and cylinders)	37	16	H	7		Crystolon	Vitrified
Surfacing (straight wheels)	37	30	J	8		Crystolon	Vitrified
Snagging (low speed)	37	16	S	5		Crystolon	Vitrified
		30	R	7	B	Alundum	Vitrified
Snagging (low speed portable)	37	16	S	5		Crystolon	Vitrified
Snagging (high speed)	37	16	S	2	T3	Crystolon	Bakelite
Chain links (annealed malleable iron and steel):							
Snagging (low speed)		20	Q	8	B	Alundum	Vitrified
Snagging (high speed)		16	P	4	T2	Alundum	Bakelite
Chasers (thread):							
Surfacing	38	46	J	5	B	Alundum	Vitrified
Grinding throats		60	M	4	L	Alundum	Shellac
Chilled iron:							
Snagging (high speed)	37	16	Q	2	T2	Crystolon	Bakelite
Snagging (low speed)	37	16	R	5		Crystolon	Vitrified
Surfacing (cups and cylinders)	38	24	I	8	B	Alundum	Vitrified
Surfacing (straight wheels)	37	36	I	8		Crystolon	Vitrified
Cylindrical (see Rolls)							
Chisels (air-driven):		24	Q			Alundum	Vitrified
Chromium plating:							
Good commercial finish	38	60	L	5	B	Alundum	Vitrified
Excellent commercial finish		80	K	5	L	Alundum	Shellac
High finish		500	I	9	L	Alundum	Shellac
Commutators:							
Rough (resurfacing stones)	37	50	K	3	L	Crystolon	Shellac
Finish (resurfacing stones)	37	100	K	5	L	Crystolon	Shellac
Rough and finish (wheel)	37	60	M	4	L	Crystolon	Shellac
Connecting rods:							
Internal	38	60	K			Alundum	Vitrified
Surfacing (cups and cylinders)	38	24	J	8	B	Alundum	Vitrified
Copper:							
Tubes (cylindrical)	37	70	J	5	L	Crystolon	Shellac
Cylindrical (also see Rolls)		60	L	4	L	Alundum	Shellac

NORTON GRINDING-WHEEL RECOMMENDATIONS.—*Continued*

Work—Material—Operation	Abrasive	Grain	Grade	Structure	Bond	Abrasive (Trade Mark)	Bonding Process
Copper *Cont.:*							
Cutting-off (low speed).	37	24	R		R	Crystolon	Rubber
Surfacing (cups and cylinders)	37	14	I	7		Crystolon	Vitrified
Couplers and draw bars:							
Snagging (slow speed).		10	U			Alundum	Vitrified
Snagging (high speed).		12	R	4	T2	Alundum	Bakelite
Crankshafts:							
Airplane	38	60	K	5	B	Alundum	Vitrified
Diesel		46	L	5	B	Alundum	Vitrified
Crankshafts, automotive: (pins and bearings)							
Rough—heavy-side removal		36	Q	3		Alundum	Vitrified
light-side removal		46	P	5		Alundum	Vitrified
Finish		50	N	5		Alundum	Vitrified
Rough and finish		46	O	5		Alundum	Vitrified
Cutlery:							
Knives—butcher							
Hemming							
Carbon steel		46	M	4	L	Alundum	Shellac
Stainless steel		46	L	4	L	Alundum	Shellac
Offhand							
Surfacing sides		150	I		S	Alundum	Silicate
Knives—paring							
Hemming							
Carbon steel		100	P	6	V	Alundum	Shellac
Stainless steel		100	O	6	V	Alundum	Shellac
Knives—pocket							
Hemming							
Carbon steel		100	P	6	V	Alundum	Shellac
Offhand—rough		100	N		S	Alundum	Silicate
finish		220	Q		S	Alundum	Silicate
Swaging		60	Q	5	B	Alundum	Vitrified
Backs		46	P	5	B	Alundum	Vitrified
Tangs		60	P	5	B	Alundum	Vitrified
Edging	37	400	O			Crystolon	Vitrified
Knives—table							
Hemming							
Carbon steel		60	M	4	L	Alundum	Shellac
Stainless steel		60	L	4	L	Alundum	Shellac
Cylinders, automotive (cast iron):							
Internal (wheels)	37	36	H	9		Crystolon	Vitrified
Honing (new cylinders, sticks) Commercial finish	37	150	M	7		Crystolon	Vitrified
Honing (new cylinders, sticks) Mirror finish	37	500	J			Crystolon	Vitrified
Rehoning, (sticks, roughing)	37	60	N	5		Crystolon	Vitrified
Rehoning (sticks, finishing)	37	120	L	6		Crystolon	Vitrified
Dies (forging), cleaning		60	P			Alundum	Vitrified

Norton Grinding-Wheel Recommendations.—*Continued*

Work—Material—Operation	Abrasive	Grain	Grade	Structure	Bond	Abrasive (Trade Mark)	Bonding Process
Dies (threading), chamfering (cone wheel)		80	Q	5	B	Alundum	Vitrified
Dies (drawing):							
Cleaning		60	L	5	B	Alundum	Vitrified
Surfacing (cups and cylinders)	38	24	J	8	B	Alundum	Vitrified
Surfacing (straight wheels)	38	46	I	8	B	Alundum	Vitrified
Drills:							
Cutting-off (high speed)		36	R	8	T2	Alundum	Bakelite
Cutting-off (low speed)		60	P	7	T2	Alundum	Bakelite
Cylindrical		50	N	5	B	Alundum	Vitrified
Centerless (soft) through feed		60	M	5	B	Alundum	Vitrified
Centerless (hard) in feed		80	N	6	B	Alundum	Vitrified
Precision sharpening	38	46	M	5	B	Alundum	Vitrified
Point thinning		60	N	5	B	Alundum	Vitrified
Drills (small):							
Fluting		46	R	0	R	Alundum	Rubber
Offhand sharpening		60	N	5	B	Alundum	Vitrified
Offhand sharpening		60	R	0	R	Alundum	Rubber
Drills (large):							
Fluting		46	P	5	B	Alundum	Vitrified
Offhand sharpening (wet)		36	P	5	B	Alundum	Vitrified
Files, surfacing		36	O	5	B	Alundum	Vitrified
Forgings:							
Centerless		60	M	5	B	Alundum	Vitrified
Cylindrical		46	M	5	B	Alundum	Vitrified
Snagging (high speed)		16	P	4	T2	Alundum	Bakelite
(low speed)		20	Q	8	B	Alundum	Vitrified
Frogs and switches (manganese steel):							
Offhand grooving (portable machines)		14	Q	5	B	Alundum	Vitrified
Semi-precision grooving (planer-type machines)		16	Q	5	B	Alundum	Vitrified
Snagging		14	R	4	T3A	Alundum	Bakelite
Surfacing		14	Q	6		Alundum	Vitrified
Gages (plug), cylindrical	38	80	K	6	B	Alundum	Vitrified
Gages (U. S. thread, coarse pitch), grinding threads	38	120	K			Alundum	Vitrified
Gages (U. S. thread, medium pitch), grinding threads	38	220	M			Alundum	Vitrified
Gages (U. S. thread, fine pitch), grinding threads	38	220	M			Alundum	Vitrified
Gears (cast iron), cleaning between teeth (offhand)	37	36	R	0	R	Crystolon	Rubber
Gears (hardened steel):							
Form precision grinding	38	60	K	5	B	Alundum	Vitrified

NORTON GRINDING-WHEEL RECOMMENDATIONS.—*Continued*

Work—Material—Operation	Abrasive	Grain	Grade	Structure	Bond	Abrasive (Trade Mark)	Bonding Process
Gears (hardened steel) *Cont.*:							
Generative precision grinding	38	60	J	5	B	Alundum	Vitrified
Internal	38	46	L			Alundum	Vitrified
		46	L	5		Alundum	Vitrified
Surfacing (cups and cylinders)	38	30	I	8	B	Alundum	Vitrified
Surfacing (straight wheels)	38	46	J	5	B	Alundum	Vitrified
Gears (untreated)	38	24	M	5	B	Alundum	Vitrified
Glass (tubing):							
Cutting-off (low speed, wet)	37	120	R	0	R	Crystolon	Rubber
Cylindrical	37	36	J	6		Crystolon	Vitrified
Internal	37	60	H	9		Crystolon	Vitrified
Nicking	37	180	S			Crystolon	Vitrified
Glass (windshield):							
Rounding corners		150	N			Alundum	Vitrified
Semipolishing edges		150	N			Alundum	Vitrified
Granite:							
Coping	37	24	Q	3	T4	Crystolon	Bakelite
Surfacing and moulding	37	40	K			Crystolon	Vitrified
Surfacing (portable)	37	14	J	5	T2	Crystolon	Bakelite
Guide bars:							
Surfacing (segments or cylinders)		16	M	8	B	Alundum	Vitrified
Surfacing (straight wheels)		24	K	8	B	Alundum	Vitrified
Hammers (claw):							
Grinding between claws		46	R	0	R	Alundum	Rubber
Neck grinding		24	Q	5	B	Alundum	Vitrified
Housing (automobile axle):							
Cylindrical		46	N	5	B	Alundum	Vitrified
Snagging { slow speed		14	R	7	B	Alundum	Vitrified
Snagging { high speed		14	R	4	T2	Alundum	Bakelite
Surfacing (segments)		16	O	8	B	Alundum	Vitrified
Knives (machine):							
Chipper and barker, sharpening		36	K	5	B	Alundum	Vitrified
Hog, sharpening		36	K	5	B	Alundum	Vitrified
Leather fleshing, sharpening (bricks)		36	P	5	B	Alundum	Vitrified
Leather shaving, sharpening—cylindrical		50	P	8	B	Alundum	Vitrified
Leather splitting, sharpening		30	J	3	L	Alundum	Shellac
Moulding, offhand sharpening		36	N	5	B	Alundum	Vitrified
Machine, sharpening		36	J	5	B	Alundum	Vitrified
Paper, sharpening		36	J	5	B	Alundum	Vitrified
Section, bevelling		36	M	5	B	Alundum	Vitrified
Surfacing backs		46	J	5	B	Alundum	Vitrified
Sugar beet, routing		46	O	3	L	Alundum	Shellac
Veneer, sharpening		36	J	5	B	Alundum	Vitrified
	19	36	J		S	Alundum	Silicate

NORTON GRINDING-WHEEL RECOMMENDATIONS.—*Continued*

Work—Material—Operation	Abrasive	Grain	Grade	Structure	Bond	Abrasive (Trade Mark)	Bonding Process
Links (locomotive), machine grinding		36	Q	5	B	Alundum	Vitrified
Machine-shop grinding, general offhand		30	P	5	B	Alundum	Vitrified
Malleable iron, annealed:							
Snagging (slow speed)		16	R	7	B	Alundum	Vitrified
Snagging (high speed)		16	Q	4	T2	Alundum	Bakelite
Snagging (unicast wh.)		20	Q	8	B	Alundum	Vitrified
Malleable iron, annealed:							
Snagging (slow speed)	37	16	T	5		Crystolon	Vitrified
Snagging (unicast)	37	16	R	5		Crystolon	Vitrified
Metallographic specimens:							
1st operation		46	N	3	L	Alundum	Shellac
2d operation	37	240	N			Crystolon	Vitrified
3d operation	37	XF	M			Crystolon	Vitrified
Monel metal:							
Cutting-off		36	P	8	T2	Alundum	Bakelite
Snagging		24	Q	5	B	Alundum	Vitrified
Cylindrical		46	L	5	B	Alundum	Vitrified
Needles, pointing		70	Q			Alundum	Vitrified
Nitralloy:							
Before nitriding		36	J			Alundum	Vitrified
After nitriding	37 38	100 60	I H	 8	 B	Crystolon Alundum	Vitrified Vitrified
Pipe (cast iron), internal)	37 37	14 16	T R	5 4	 T3	Crystolon Crystolon	Vitrified Bakelite
Pipe (soft steel):							
Cutting-off		36	S	8	T2	Alundum	Bakelite
Internal		20	P			Alundum	Vitrified
Piston pins:							
Centerless machine							
Roughing		60	M	5	B	Alundum	Vitrified
Semifinishing		60	M	5	B	Alundum	Vitrified
Finishing	37	320	N	8	L	Crystolon	Shellac
Piston rings (cast iron or semisteel):							
Surfacing rough (cylinders)	38	30	H	8	B	Alundum	Vitrified
Surfacing (straight wheels)		50	L	5	B	Alundum	Vitrified
Internal (snagging)	37	36	R			Crystolon	Vitrified
Piston rods (locomotive), cylindrical		46	M	5	B	Alundum	Vitrified
Pistons (aluminum):							
Cylindrical	37	36	J	7		Crystolon	Vitrified
Centerless	37	46	I	5		Crystolon	Vitrified
Regrinding	37	46	K	5		Crystolon	Vitrified
Pistons (cast iron):							
Cylindrical	37	36	K	7		Crystolon	Vitrified
Centerless	37	46	J	6		Crystolon	Vitrified
Regrinding	37	46	K	5		Crystolon	Vitrified
Plows (steel):							
Surfacing		20	Q	5	B	Alundum	Vitrified
Fitting		24	R	7	B	Alundum	Vitrified
Edging and jointing		16	S			Alundum	Vitrified

NORTON GRINDING-WHEEL RECOMMENDATIONS.—*Continued*

Work—Material—Operation	Abrasive	Grain	Grade	Structure	Bond	Abrasive (Trade Mark)	Bonding Process
Plows (chilled iron), all operations, wet		20	R	7	B	Alundum	Vitrified
dry		20	N	5	B	Alundum	Vitrified
Pulleys (cast iron):							
Cylindrical	37	30	J	8		Crystolon	Vitrified
Rough with pulley grinder (cylinder wheel)	37	24	I	8		Crystolon	Vitrified
Finish with pulley grinder (cylinder wheel)		[illegible]	N	0	R	Alundum	Rubber
Rails (surfacing welds):							
Wheels (slow speed)		24	R	5	B	Alundum	Vitrified
Wheels (high speed)		16	Q	4	T3A	Alundum	Bakelite
Bricks		24	M	5	B	Alundum	Vitrified
		16	N	5	B	Alundum	Vitrified
Razors (straight):							
Burring		46	P	5	B	Alundum	Vitrified
Side of tang		60	O	5	B	Alundum	Vitrified
Concaving		60	P	8	B	Alundum	Vitrified
Shoulders (shaping after hardening)		120	M			Alundum	Vitrified
Edging (roughing)	38	80	K	6	B	Alundum	Vitrified
Edging (finishing)		220	J	5	L	Alundum	Shellac
Razors (safety), sharpening		220	N	5	L	Alundum	Shellac
Reamers:							
Backing off	38	46	K	5	B	Alundum	Vitrified
Cylindrical	38	46	M	5	B	Alundum	Vitrified
Fluting	38	46	L	5	B	Alundum	Vitrified
Rifle barrels, cylindrical		46	M	5	B	Alundum	Vitrified
Rim (automobile):							
Removing welds (high speed)		20	R	0	R	Alundum	Rubber
Grooving		24	R		R	Alundum	Rubber
Roller bearing cups:							
Centerless O.D.		80	L	7	B	Alundum	Vitrified
Internal		70	N	5	B	Alundum	Vitrified
Rollers for bearings:							
Centerless—roughing		80	O	8	B	Alundum	Vitrified
finishing		90	R		R	Alundum	Rubber
Rolls (brass or copper):							
Cylindrical—roughing	37	46	L	3	L	Crystolon	Shellac
finishing	37	100	I	9		Crystolon	Vitrified
Rolls (cast iron):							
Cylindrical (rough)	37	30	K	5		Crystolon	Vitrified
Cylindrical (finish)	37	80	J	7		Crystolon	Vitrified
Rolls (alloy chilled iron)	37	20	Q	4	T2	Crystolon	Bakelite
Rolls (chilled iron):							
Farrell-type machine							
Roughing	37	30	L	5	L	Crystolon	Shellac
	37	36	L	5	T2	Crystolon	Bakelite
Finishing	37	70	J	4	L	Crystolon	Shellac
Norton-type machine							
Cylindrical (hot-plate rolls)	37	24	N	5		Crystolon	Vitrified
Cylindrical (dryer rolls)	37	46	J	6		Crystolon	Vitrified

NORTON GRINDING-WHEEL RECOMMENDATIONS.—*Continued*

Work—Material—Operation	Abrasive	Grain	Grade	Structure	Bond	Abrasive (Trade Mark)	Bonding Process
Rolls (hard rubber):							
Cylindrical (rough and finish)	37	36	K	5		Crystolon	Vitrified
Rolls (soft rubber):							
Cylindrical (rough)	37	24	K	5	T2	Crystolon	Bakelite
Cylindrical (finishing)	37	60	K	5	T2	Crystolon	Bakelite
Rolls (steel, hardened):							
Farrell-type machine							
Roughing		80	M	5	L	Alundum	Shellac
Finishing	37	320	I	8	L	Crystolon	Shellac
Norton-type machine							
Cylindrical	38	46	L	5	B	Alundum	Vitrified
Cylindrical (polishing)	37	500	I	9	L	Crystolon	Shellac
Rubber (inking rolls)	37	60	K	5	T2	Crystolon	Bakelite
Sad irons:							
Surfacing (cups and cylinders)	38	14	I	8	B	Alundum	Vitrified
Surfacing (offhand)	37	16	N	5		Crystolon	Vitrified
Snagging	37	16	Q	5		Crystolon	Vitrified
Safes:							
Snagging		16	P	5	B	Alundum	Vitrified
Surfacing		20	O	8	B	Alundum	Vitrified
Sand cores, cutting-off	37	24	P	5	T2	Crystolon	Bakelite
Saws (band), gumming	19	46	M			Alundum	Vitrified
		46	M	5	B	Alundum	Vitrified
		36	O	7	T	Alundum	Bakelite
		30	O	3	L	Alundum	Shellac
Saws (circular), gumming	19	46	M			Alundum	Vitrified
		46	M	5	B	Alundum	Vitrified
Saws (metal cutting), gumming		60	P			Alundum	Vitrified
Scissors and shears (cast iron):							
Surfacing sides of blades	37	100	S			Crystolon	Vitrified
Scissors and shears (steel):							
Surfacing sides of blades (cyl.)		150	O	5	V	Alundum	Shellac
Grinding flash from bows		46	P			Alundum	Vitrified
Pointing and shaping		50	O			Alundum	Vitrified
Grinding neck or corner		120	N	5	L	Alundum	Shellac
Strike-cutting edges		120	M			Alundum	Vitrified
Resharpening (small wheels)	38	100	M	8	B	Alundum	Vitrified
(large wheels)		100	M		S	Alundum	Silicate
Shovels, edging		30	R	7	B	Alundum	Vitrified
Spline shafts:							
Centerless		50	N	5	B	Alundum	Vitrified
Cylindrical		50	O	5	B	Alundum	Vitrified
Surfacing splines		50	L	5	B	Alundum	Vitrified
Springs (leaf):							
Grinding eyes		20	P	5	B	Alundum	Vitrified
Chamfering		20	S			Alundum	Vitrified
Springs (coil), squaring ends—small		30	O	5	B	Alundum	Vitrified
large		16	N	5	B	Alundum	Vitrified

NORTON GRINDING-WHEEL RECOMMENDATIONS.—*Continued*

Work—Material—Operation	Abrasive	Grain	Grade	Structure	Bond	Abrasive (Trade Mark)	Bonding Process
Steel (hardened):							
Centerless	38	60	M	5	B	Alundum	Vitrified
Cylindrical	38	46	L	5	B	Alundum	Vitrified
Surfacing (cups and cylinders)	38	30	G	8	B	Alundum	Vitrified
Surfacing (straight wheels)	38	36	H	8	B	Alundum	Vitrified
Cutting-off		46	Q	8	T2	Alundum	Bakelite
Internal	38	60	J			Alundum	Vitrified
Steel (soft):							
Centerless		60	M	5	B	Alundum	Vitrified
Cylindrical		46	N	5	B	Alundum	Vitrified
Surfacing (cups and cylinders)	38	16	K	8	B	Alundum	Vitrified
Surfacing (straight wheels)	38	36	L	8	B	Alundum	Vitrified
Cutting-off		24	S	8	T2	Alundum	Bakelite
Internal grinding	38	46	L			Alundum	Vitrified
Steel (high speed):							
Centerless		60	L	5	B	Alundum	Vitrified
Cylindrical	38	46	L	5	B	Alundum	Vitrified
Surfacing (cups and cylinders)	38	46	G	8	B	Alundum	Vitrified
Surfacing (straight wheels)	38	46	H	8	B	Alundum	Vitrified
Cutting-off		46	Q	8	T2	Alundum	Bakelite
Internal	38	46	J			Alundum	Vitrified
High speed		14	Q	4	T2	Alundum	Bakelite
Snagging (unannealed billets)							
Slow speed		16	P	5	B	Alundum	Vitrified
High speed		16	M	2	T2	Alundum	Bakelite
Steel (stainless):							
Centerless	37	50	M	9		Crystolon	Vitrified
Cylindrical	37	46	M	5		Crystolon	Vitrified
Surfacing	38	36	H	8	B	Alundum	Vitrified
Cutting-off		36	Q	8	T2	Alundum	Bakelite
Snagging (billets, high speed)		12	S	4	T3A	Alundum	Bakelite
Steel castings (low carbon):							
Swing frame (high speed)		14	Q	4	T2	Alundum	Bakelite
Floor stand (high speed)		20	P	4	T2	Alundum	Bakelite
Steel castings (manganese):							
(see also Frogs and Switches)							
Snagging (high-speed swing frame)		14	R	4	Ts	Alundum	Bakelite
Snagging (high-speed floor stand)		20	Q	4	T2	Alundum	Bakelite
Stellite:							
Cylindrical		46	M	5	B	Alundum	Vitrified
Offhand (tools)		46	N	5	B	Alundum	Vitrified

NORTON GRINDING-WHEEL RECOMMENDATIONS.—*Continued*

Work—Material—Operation	Abrasive	Grain	Grade	Structure	Bond	Abrasive (Trade Mark)	Bonding Process
Stellite *Cont.:*							
Surfacing (cups and cylinders)		50	G	8	B	Alundum	Vitrified
Surfacing (straight wheels)	38	46	H	8	B	Alundum	Vitrified
Drills (pointing—machine)	38	46	L	5	B	Alundum	Vitrified
(pointing—hand)		60	M	5	B	Alundum	Vitrified
Cutting-off (low speed)		60	P	7	T2	Alundum	Bakelite
Tool and cutter	38	46	J	5	B	Alundum	Vitrified
Stove parts (cast iron):							
Snagging	37	24	T	5		Crystolon	Vitrified
Taps:							
Squaring ends		60	N	5	B	Alundum	Vitrified
Grinding relief	38	80	J	6	B	Alundum	Vitrified
Fluting (small taps)		60	R		R	Alundum	Rubber
(large taps)	38	46	L	5	B	Alundum	Vitrified
Threading	38	150	L			Alundum	Vitrified
Shanks (cylindrical)	38	80	M	6	B	Alundum	Vitrified
Tools (lathe and planer):							
(Carbon and H.S.S.)							
Light (offhand)							
roughing		36	O	5	B	Alundum	Vitrified
finishing		60	N	5	B	Alundum	Vitrified
Heavy (offhand)		30	O	5	B	Alundum	Vitrified
Heavy (large wheels)		24	P		S	Alundum	Silicate
Automatic (cup wheel)		24	M	5	B	Alundum	Vitrified
Automatic (straight wheel)		24	M	5	B	Alundum	Vitrified
Fixture grinding	38	46	K	5	B	Alundum	Vitrified
(see also Tungsten Carbide Alloys)							
Tubes (steel):							
Centerless		60	N	5	B	Alundum	Vitrified
Cutting-off		60	R	2	R1D	Alundum	Rubber
Tungsten and tantalum carbide alloys:							
Offhand roughing	37	60	I	9		Crystolon	Vitrified
Offhand semifinishing	37	80	H	9		Crystolon	Vitrified
Offhand finishing	37	100	H	9		Crystolon	Vitrified
Fixture grinding (semi-offhand)							
Rough sellers	37	60	I	9		Crystolon	Vitrified
Gisholt	37	60	I	9		Crystolon	Vitrified
Sundstrand	37	60	F	9		Crystolon	Vitrified
Semifinish sellers	37	80	I	9		Crystolon	Vitrified
Gisholt	37	80	H	9		Crystolon	Vitrified
Sundstrand	37	90	F	9		Crystolon	Vitrified
Surface grinding (B & S type) dry							
Rough (tungsten)	37 37	80 60	G H	9 9		Crystolon Crystolon	Vitrified Vitrified
Finish (tungsten)	37	100	G	9		Crystolon	Vitrified
Rough (tantalum)	37	80	G	9		Crystolon	Vitrified
Finish (tantalum)	37	100	F	9		Crystolon	Vitrified
Hydraulic (wet)							

NORTON GRINDING-WHEEL RECOMMENDATIONS.—*Continued*

Work—Material—Operation	Abrasive	Grain	Grade	Structure	Bond	Abrasive (Trade Mark)	Bonding Process
Tungsten and tantalum carbide alloys *Cont.:*							
Rough	37	60	I	9		Crystolon	Vitrified
Finish	37	100	H	9		Crystolon	Vitrified
Form grinding	37	100	H	9		Crystolon	Vitrified
Sharp angles	37	280	H	9		Crystolon	Vitrified
Backing-off	37	60	H	9		Crystolon	Vitrified
Milling cutters (cups)	37	80	G	9		Crystolon	Vitrified
Milling cutters—straight wheels	37	60	I	9		Crystolon	Vitrified
Cylindrical							
Rough	37	60	I	9		Crystolon	Vitrified
Finish	37	100	H	9		Crystolon	Vitrified
Internal	37	46	K	8		Crystolon	Vitrified
Lapping (C. I. plate)		280				Norbide* Grain	
Lapping—coarse		100				Diamond	Bakelite
Lapping—medium		200				Diamond	Bakelite
Lapping—fine		320				Diamond	Bakelite
Centerless	37	80	I	9		Crystolon	Vitrified
Tungsten rods:							
Cutting-off		150	R	7	R1D	Alundum	Rubber
Centerless	37	60	J	9		Crystolon	Vitrified
Valve seat inserts:							
Cast iron (roughing)	37	46	M			Crystolon	Vitrified
Alloy steel (roughing)	38	60	N	6	B	Alundum	Vitrified
Stellite (roughing)	38	80	I	8	B	Alundum	Vitrified
All seats (finishing)	37	150	L			Crystolon	Vitrified
Valve tappets:							
Facing (special tappet grinder)	38	60	L	5	B	Alundum	Vitrified
Centerless		80	P	8	B	Alundum	Vitrified
Cylindrical		46	M	5	B	Alundum	Vitrified
Valves (automobile):							
Grinding seats		80	O	5	B	Alundum	Vitrified
Cylindrical grinding stems		46	N	5	B	Alundum	Vitrified
Cutting-off stems		30	W	7	T3	Alundum	Bakelite
Centerless grind stems		60	O	5	B	Alundum	Vitrified
Welds:							
Smoothing (high speed)	24	24 20	R R	4 0	T2 R	Alundum Alundum	Bakelite Rubber
Smoothing (slow speed)		24	Q	8	B	Alundum	Vitrified
Wood (hard), centerless	37	24	K			Crystolon	Vitrified
Worms, grinding threads	38	36	L	5	B	Alundum	Vitrified
Wrenches, snagging		24	Q	5	B	Alundum	Vitrified
Wrought iron, snagging		16	R	7	B	Alundum	Vitrified

* Trade mark registered, U. S. Patent Office for Norton Boron Carbide, B_4C.

GRINDING ALLOWANCES FOR VARIOUS LENGTHS AND DIAMETERS

The following table gives the allowances of the Brown & Sharpe Mfg. Co. in rough turning work for the grinding department. Limit gages of the "snap" type are used, the dimensions in the table covering work up to 2 inches diameter.

LIMIT GAGE SIZES FOR LATHE WORK WHICH IS TO BE FINISHED BY GRINDING
BROWN & SHARPE MFG. CO.

Size	Not go on	Go on	Size	Not go on	Go on	Size	Not go on	Go on
Inches			Inches			Inches		
3/8	0.383	0.387	15/16	0.9455	0.9495	1 1/2	1.508	1.512
7/16	0.4455	0.4495	1	1.008	1.012	1 9/16	1.5705	1.5745
1/2	0.508	0.512	1 1/16	1.0705	1.0745	1 5/8	1.633	1.637
9/16	0.5705	0.5745	1 1/8	1.133	1.137	1 11/16	1.6955	1.6995
5/8	0.633	0.637	1 3/16	1.1955	1.1995	1 3/4	1.758	1.762
11/16	0.6955	0.6995	1 1/4	1.258	1.262	1 13/16	1.8205	1.8245
3/4	0.758	0.762	1 5/16	1.3205	1.3245	1 7/8	1.883	1.8875
13/16	0.8205	0.8245	1 3/8	1.383	1.387	1 15/16	1.9455	1.949
7/8	0.883	0.887	1 7/16	1.4455	1.4495	2	2.008	2.012

MAGNETIC CHUCKS

Magnetic chucks have come to be a very necessary part of the equipment of any surface-grinding machine, whether plain or rotary. Before their coming it was customary to bed thin work in wax on the platen of a grinder in order to finish the flat sides. Other flat work had to be held in "fingers" on special fixtures, and on account of their being very thin and easily sprung, it was difficult to secure really accurate work.

The magnetic chuck holds the thinnest pieces of iron or steel firmly, draws down any slight spring in the work, and prevents springing when strains are released during the grinding operations.

The chuck face is divided into magnet poles, separated by babbitt, or other nonmagnetic metals, and coils of insulated wire from these poles into electromagnets when current is applied. For rotary work, the electric current is supplied by brushes running against insulated contact rings on the outside. Current can be supplied from any incandescent-lamp socket on a direct-current circuit.

Alternating current cannot be used.

A chuck having a face 10 × 14 inches uses about one-half as much power as a 16 candle-power lamp.

Hints for Using Magnetic Chucks

The chucks should not be taken apart.

Nothing but iron or steel can be held on the chucks.

The holding power depends on the amount of work surface in contact with the chuck.

Work can be held on edge by using adjustable back rest.

Very thin work can be held for grinding on the edges by laying it against the back rest and backing it up with a parallel strip.

Thin work will not hold so well as thick work.

In packing a number of small pieces on a chuck at one setting, it is better to separate them a little with strips of non-magnetic material.

Do not plug up the vent holes in the chuck.

Keep water away from the switch, the brushes, and the interior of the chuck.

Magnetic chucks do not take the place of all other chucks.

Do not use water on chucks except where they are made for it.

Chucks are usually wound for 110 or 220 volts *for direct current only.*

Permanent-Magnet Chucks

Permanent-magnet chucks, which avoid the necessity for any electrical connections, are made by the Brown & Sharpe Mfg. Co. Special alloy magnets are strong enough for grinding operations and for light lathe work, when made in round form. A movable chuck face by-passes the magnetic flux when the handle is turned to the "off" position.

After placing the work, a movement of the handle sends the magnetic flux through the work. The amount of holding power can be varied by the position of the handle. With the face of the chuck partially energized, the work can be easily tapped into exact position. With wet grinding there is no danger of damaging the chuck in any way.

CENTERLESS GRINDING

Modern centerless grinding machines comprise a high-speed grinding wheel and an opposed slowly moving regulating wheel, forming a grinding throat. A work rest suitably supports the work in this throat and the several parts are relatively adjustable for different sizes and varieties of work.

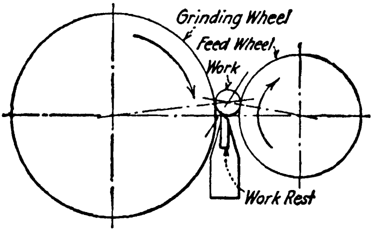


FIG. 13.—Centerless Grinding

The action of the grinding wheel forces the work against the work rest owing to the cutting pressure and also against the regulating wheel by virtue of what may be called the "cutting contact" pressure. This pressure, aided by the gravity component of the work, keeps the piece being ground in contact with the regulating wheel. This wheel provides a continuously advancing frictional surface ensuring constant and uniform rotation of the work at the same peripheral velocity as that of the regulating wheel.

Average roughing cuts are from 0.005 to 0.008 inch per pass, and finishing cuts range from 0.003 to 0.0015 inch per pass. When work is relatively straight but out of round, the regulating wheel should be set at a slight angle, giving a small lap per revolution. When pieces are warped, as from hardening, an angle of 5 or 6 degrees will give a wide lap per revolution and straighten the work. With the proper angle for best results, the speed of the regulating or feed wheels should be increased to the limit established by the requirements of accuracy and production.

There are three main classes of centerless grinding, namely, through-feed, in-feed, end-feed.

Through-Feed

Through-feed grinding is accomplished, as the name implies, by passing the work through or between the grinding and regulating wheels. Grinding takes place as the work passes from one side of the wheels to the other. Obviously, since all points on the work pass all contact points between the wheels, only straight cylindrical surfaces without interfering shoulders can be ground by this method.

The axial movement of the work past the grinding wheel is imparted by the regulating wheel.

Machine is arranged in such a manner that the regulating wheel can be swung about a horizontal axis from zero to 7 or 10 degrees relative to the axis of the grinding-wheel spindle.

The speed of the regulating wheel and the diameter of the regulating wheel also influence the feeding rate of the work. It is often necessary to pass work between the wheels more than once. The number of passes is determined by the amount of stock to be removed, the condition of the work as to roundness and straightness, the quality of the material, and the limits of accuracy required.

With this method there is a fixed relation between the grinding wheel, regulating wheel, and the work-supporting blade. The wheels are adjusted so that the distance between their active surfaces, together with the height of the work blade, determines the diameter of the ground piece. The centers of the wheels are stationary during grinding operations and require slight readjustments from time to time to compensate for the wear of the grinding wheel.

A work rest or fixture, which provides means for holding the blade, incorporates adjustable guides, to both the front and rear of the wheels. These guides must be accurately aligned with the regulating wheel face to insure the work traveling in a straight line.

In-Feed

In-feed method is usually employed when grinding work that has a shoulder, head, or some portion larger than the ground diameter. The same method is used for the simultaneous grinding of several diameters of the work as well as for finishing pieces with taper, spherical, or any other irregular profile.

In general, this method corresponds to the plunge-cut or form grinding on the center-type grinder.

The length of the section or sections to be ground in any one operation is limited by the width of the grinding wheel.

As there is no relative axial movement of the work, the regulating wheel is set with its axis approximately parallel to that of the grinding wheel. A slight angle is maintained to keep work tight against an end stop.

End-Feed

The end-feed method is used only on taper work. The grinding wheel, the regulating wheel, and the blade are set in a fixed relation to each other, and the work is fed in from the front, manually or mechanically, to a fixed-end stop. Either the grinding or the regulating wheel, or both, are dressed to the proper taper.

Regardless of the method employed, the grinding of the smaller size work can be assisted by use of a magazine, gravity chute, or hopper feeds, provided the shape of the piece will permit the use of such devices.

The increase in the application of the centerless method of grinding to precision work is directly due to the following factors:

1. Saving in cost effected by the elimination of the centering operation.
2. Owing to the complete support of the work, the grinding wheel can be made to remove metal at maximum efficiency.
3. Material reduction of idle or nongrinding time in the grinding cycle.
4. The centerless-grinding method permits work to be rounded up with approximately half the surplus stock necessary for other types of cylindrical grinding which materially reduces the wheel cost per piece ground.

The modern centerless grinding machine sizes on the diameter and not on the radius, thereby automatically doubling the factor of safety in securing precision. On in-feed or plunge-cut work, the control of size is obtained by the utilization of the principle of leverage applied at a considerable radius terminating in a dead stop.

The design of the machine and the class of work on which it is generally employed lend themselves favorably to the application of automatic-hopper feeds for both through-feed and in-feed work. Another factor is the automatic compensation for grinding-wheel wear, by which means the size of work produced is automatically maintained within extremely close limits of accuracy. Centerless grinding machines are now made for internal work, which is revolved between two wheels while an internal spindle does the work.

INTERNAL GRINDING

Recommended Stock Conditions for Internal Grinding[1]

There are many factors which govern conditions of holes, such as straightness, out-of-roundness, eccentricity with the locating points, and condition of the surface in the rough hole. However, it is felt that the following will be helpful for use under general conditions, but, where pieces are ground in large quantities and stock and heat-treating conditions are carefully controlled, less stock may be left in order to reduce the cost of grinding. The figures are for the stock left in the holes as they come to the grinder, whether soft or heat-treated, and for lengths two to three times the diameter. Longer holes usually require more stock, as do out-of-round holes and those that are not true with the finished hole to be produced.

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[1] Lewis A. Hastings.

Hole Diameters, in Inches	Recommended Stock Left for Grinding, in Inches
¼ to 7/16	0.005 to 0.007
7/16 to ⅝	0.006 to 0.008
⅝ to 1	0.008 to 0.010
1 to 1½	0.010 to 0.012
1½ to 2½	0.012 to 0.015
2½ to 4	0.015 to 0.018
4 to 6	0.020 to 0.025
6 to 8½	0.025 to 0.030
8½ to 10	0.030 to 0.035

The Importance of Truing Wheels

The proper truing of grinding wheels is often neglected in internal grinding, even though it is of major importance. Wheels dressed or trued by tools held in the hand or not rigidly supported are not true in contour and the cutting surface is not parallel to the finish surface being ground, nor do such dressed wheels run in proper balance. Wheels dressed in this way will not cut free or produce the finish required.

To true or dress wheels properly for internal grinding, fixed diamonds are usually the most satisfactory and the truing member should be securely clamped and the wheel passed by the truing member with a uniform feed. Power-control feeds usually produce the best results.

Wheel Width and Diameter

It is general practice in internal grinding to use as short stubby wheel spindles as possible, and, where narrow surfaces are being ground, the wheel is usually permitted to uncover half the width of the work. However, where the width of the work is wider than the width of the wheel, the wheel usually withdraws from the hole half the width of the wheel. In this way, straight holes are obtained without bell mouthing. To aid in choosing the width of wheel for a given size of hole, the widths of wheel shown in the following table are recommended practice:

Hole Diameters, in Inches	Suggested Width of Wheel, in Inches
¼ to 1½	Use the nearest standard wheel shape that has a width approximately equal to the wheel diameter
1½ to 5	1 to 1½
5 to 10	1½ to 2

When there are short ports or openings in the hole being ground, wheels wide enough to span the openings will prevent grinding low places adjacent to the openings. Where the openings are too long to span with the wheel, narrow wheels will reduce the wheel pressure and produce more accurate surfaces. There is no definite rule which can be made to cover all conditions, as experience will determine the best wheel for a job.

The following table has been prepared to aid in obtaining the proper diameter of wheel for a given size of hole. It will be noted that there are two columns given to wheel diameters. One is for the diameter of wheel to be purchased, and the other is the diameter to dress a new wheel to make suitable for grinding. The diameter to which the new wheel is dressed is the dimension of the wheel after the first dressing and is a suitable size to commence grinding with. However, when purchasing, it is necessary to secure the next largest standard wheel for holes of larger diameter than the desired wheel. When the diameter of the wheel given is the size of the wheel before dressing, it is only necessary merely to true up the wheel in such cases.

Diameter of Hole to Be Ground, Inches	Diameter of Wheel to Purchase	Diameter to Dress a New Wheel to before Grinding to Make Suitable for Grinding	Diameter of Hole to Be Ground	Diameter of Wheel to Purchase	Diameter to Dress a New Wheel to before Grinding to Make Suitable for Grinding
1/4	1/4	7/32	3	2 1/2	2 1/2 (round up only)
5/16	5/16	9/32	3 1/4	2 3/4	2 3/4 (round up only)
3/8	3/8	11/32	3 1/2	3	3 (round up only)
7/16	7/16	13/32	3 3/4	3 1/4	3 1/4 (round up only)
1/2	1/2	15/32	4	3 1/2	3 1/2 (round up only)
9/16	9/16	17/32	4 1/4	3 1/2	3 1/2 (round up only)
5/8	5/8	9/16	4 1/2	3 1/2	3 1/2 (round up only)
11/16	5/8	5/8 (round up only)	4 3/4	3 1/2	3 1/2 (round up only)
3/4	3/4	11/16	5	4	4 (round up only)
13/16	3/4	3/4 (round up only)	5 1/4	4	4 (round up only)
7/8	7/8	13/16	5 1/2	4	4 (round up only)
15/16	7/8	7/8 (round up only)	5 3/4	4	4 (round up only)
1	7/8	7/8 (round up only)	6	4 1/2	4 1/2 (round up only)
1 1/8	1	1 (round up only)	6 1/4	4 1/2	4 1/2 (round up only)
1 1/4	1 1/8	1 1/8 (round up only)	6 1/2	4 1/2	4 1/2 (round up only)
1 3/8	1 1/4	1 1/4 (round up only)	6 3/4	4 1/2	4 1/2 (round up only)
1 1/2	1 1/4	1 1/4 (round up only)	7	5	5 (round up only)
1 5/8	1 3/8	1 3/8 (round up only)			
1 3/4	1 1/2	1 1/2 (round up only)	7 1/2	5 1/2	5 1/2 (round up only)
1 7/8	1 1/2	1 1/2 (round up only)	8	6	6 (round up only)
2	1 3/4	1 3/4 (round up only)	8 1/2	6 1/2	6 1/2 (round up only)
2 1/4	2	2 (round up only)	9	7	7 (round up only)
2 1/2	2 1/4	2 1/4 (round up only)	9 1/2	7	7 (round up only)
2 3/4	2 1/2	2 1/2 (round up only)	10	7	7 (round up only)

All measurements in inches.

Cutting-Off Wheels

Abrasive wheels for cutting are being used extensively for metals and for such materials as plastics, glass, porcelain, tile, asbestos, and

the like. Shellac, rubber, and resinoid bonds are used for these wheels. Some consider 2 inches as the maximum steel bar to be cut by this method, but some of the newer machines are cutting larger stock. Tubing is cut in much larger sizes. Shellac bonds are used in cutting tool steels. Wheels as thin as 0.005 inch are made with rubber bond for slotting pen nibs. Wheels 0.02 to 0.025 inch thick are used for cutting tungsten rods, and glass tubing is cut with wheels 0.030 to 0.062 inch thick. Resinoid bonds permit speeds up to 16,000 surface feet per minute.

Makers of cutting-off wheels should be consulted as to kind of wheel and the best speed for special materials and all unusual conditions.

Diamond Grinding Wheels

Norton diamond wheels are made of diamond (bort) particles, held in a bakelite bond and are recommended only for extremely hard materials, such as carbide tools. Surface speeds of from 4,500 to 6,000 feet are recommended, with table or work travel of from 100 to 500 *inches* per minute. Cross feeds of 0.030 to 0.060 inch and vertical or *in*-feeds of 0.00025 to 0.002 inch are recommended. Unless ample coolant can be used, the surface speed of the wheel should not exceed 3,000 feet per minute.

If wheels load or glaze from running dry, a light application of a pumice stick or fine abrasive cloth will remove the loading. A light lapping of the rim of a cup wheel with 320-grain crystolon abrasive and water on a cast-iron plate will give maximum sharpness and restore a plane surface. Light cuts on a surface of hard high-speed steel will true a straight wheel.

A grinding compound sufficiently alkaline to prevent rusting is better than oil or clear water. Light spindle oil can however be applied to the wheel by a wick where other means are not available. All wheels are of the same hardness but the grain sizes available are:

No. 100	For fastest grinding and lapping.
No. 220	For producing keen cutting edges.
No. 320	For small finishing tools and fine finishes.
No. 500	For extremely fine finishes.

The maker suggests the following precautions:

Mount the wheel so that it runs true.
Keep the wheel on its individual collet until it is worn out.
Use on extremely hard materials only.
Undercut the steel shank on cemented carbide-tipped tools before grinding the carbide.
Be sure the grinding face of the wheel is lubricated at all times.
Dress the wheel if it should become loaded or glazed.
Don't attempt to true the wheel with a diamond.
Don't remove the wheel from its collet.
Don't operate the wheel dry.
Don't grind steel or other relatively soft, tough materials, except for a light finishing cut.

POLISHING

"Polishing" is a term commonly used to designate that branch of grinding which employs various types of yielding and cushion wheels, and flexible belts, the surfaces of which are covered or impregnated with some sort of abrasive. Polishing is sometimes referred to as "flexible grinding."

Flexible- vs. Solid-Wheel Grinding

It is not possible definitely to classify all work which should be done by flexible grinding in preference to solid-wheel grinding. There is considerable overlapping, and on some jobs an actual test would have to be made in order to determine the better method to employ.

In the manufacture of small parts from sheet or strip stock, it has been found advantageous to polish the sheets or strips before stamping. The smoother surface decreases wear and tear on dies, and the fabricated part requires only such "touch-up" polishing as may be necessary to remove slight drawing or stamping marks. Automatic machines are now available for polishing sheet metals.

Parts or surfaces of irregular contour which require the reduction of size or shape to approximate dimensions can usually be ground economically on flexible wheels, provided the amount of material to be removed is not too great. Good examples of flexible grinding of this kind are the surfacing of plows and the shaping of axes.

As a rule flexible wheels tend to follow the original contour of the surface being ground, and, if it is necessary to materially change the shape of a part, it is better to use solid wheels. Work which has been ground with solid wheels is frequently polished or buffed afterwards, and, if the grinding has been accurately done, the polished surface will possess accuracy as well as luster.

Types of Wheels and Belts

There are many types of wheels and belts used for flexible grinding and polishing, each of which has certain characteristics which adapt it to certain kinds of work.

Cloth polishing wheels are made by gluing together sections of sewed pieced buffs. They are used for much the same class of work as the disc canvas wheels but are softer and more flexible.

Wool-felt wheels are manufactured from discs of woven felt from $\frac{3}{16}$ to $\frac{1}{4}$ inch thick. They provide a stiffer wheel than the cloth polishing wheel, owing to the thickness of the felt discs. They hold a flatter face and have less tendency to mush or round over on the corners.

Solid-felt wheels are made from a fine grade of felt in several qualities—fine or coarse. When coated with abrasives, they provide a wheel with a yielding character but with a face which is solid and unbroken as differentiated from wheels built up of discs.

Walrus hide, because of its great thickness and open porous character, is very valuable for making polishing wheels. It is possible to make wheels up to $1\frac{1}{2}$ inches thick from a single piece of this hide. It is used for certain fine finishes. It is extensively used in the silver and jewelry trades with the finer grades of powdered abrasives applied by moistening the abrasives and simply forcing them into the pores or fibers of the leather. Walrus wheels are occasionally used with the coarser abrasives glued on in the manner common to other wheels.

Sheepskin wheels are made by cementing or sewing together discs of sheepskin. The cemented wheels are quite soft, but the sewed ones are even more so. These wheels are suitable for fine finishing and buffing of soft metals. The hand-sewed wheel is used extensively in the jewelry trade.

Leather-covered wheels are made of laminated wood centers covered with a strip of "back" leather, the best quality of the hide usually used in belting. These are in common use and are particularly adapted for flat work and for work where it is necessary to maintain sharp corner outlines.

Leathers of various thicknesses and degrees of hardness can be used to suit individual conditions.

Bull-neck wheels are made by cementing together discs of bull-neck leather of fairly uniform thickness. Bull-neck leather, as differentiated from back leather, is softer, more spongy, and has a more open grain. The hardness and quality of the wheels can be varied by using leathers of different thicknesses, thick discs making softer wheels than thin discs.

Disc canvas wheels are usually of two general kinds of construction, the glued wheels and hand-sewn wheels. The hardest wheels are those made by gluing together the individual discs of canvas into a solid wheel. More flexible wheels are manufactured by sewing together several layers of the canvas into sections and then gluing the sections together into the solid wheel. The flexibility of the face may be increased by not gluing the sections all the way out to the periphery.

Compress polishing wheels are made from rectangular pieces of leather, canvas, felt, paper, or other material arranged radially and compressed to form a ring or cushion. This ring is assembled between two metal side plates which engage in annular grooves in the sides of the ring and hold the section intact.

Buffs

Buffs are manufactured in two general forms—loose or open buffs and sewed pieced buffs. The loose buffs are made from closely woven firm cotton fabrics of various grades and weaves as may be required. Each layer is a full-size disc. These are usually held together with one row of sewing near the center hole.

Sewed pieced buffs are manufactured with the discs comprised of several strips or pieces with outside full discs as covers, the whole assembly held together with rows of machine sewing usually $\frac{1}{4}$ or $\frac{3}{8}$ inch apart.

Both of these buffs are used with tripoli, crocus, levigated alumina, rouge, and other buffing compositions. Sewed pieced buffs are extensively used in the manufacture of the cloth polishing wheels. Buffs made of Canton flannel or wool are used on such materials as hard rubber, Bakelite, and precious metals.

Polishing belts are endless and are usually made of canvas. These are sometimes supported on leather belts and sometimes cushion wheels are used as a backing for the belt. On some classes of work, these belts are very efficient.

Importance of Proper Grain

The abrasive grain used in connection with flexible grinding or polishing is of great importance because it is the cutting or abrading medium which does the actual work. Natural abrasives were formerly used almost exclusively, but artificial abrasives of the aluminous type have very largely displaced them. Silicon carbide abrasives are seldom used for polishing.

The quality of natural abrasives cannot be controlled. Even the best grades may contain as high as 35 to 40 per cent impurities, largely iron oxide. The better grades of artificial aluminum oxide abrasives contain approximately 95 per cent crystalline alumina, and this percentage is maintained within very close limits. This uniformly high percentage of crystalline alumina is what gives the artificial abrasives their superiority over the natural abrasives. This superiority is more apparent in the coarser grains which are used on operations involving the removal of considerable material.

The abrasives used are designated by number as in grinding wheels, running from 8 to 600 for this work.

Selection of Proper Size

Some work involves the removal of very little material and can be done with a single "polishing" operation. Other jobs require two, three or even more operations starting with coarser and finishing with finer grain. If coarse grain (say, No. 36) is used in the first operation, this should not be followed by a very fine grain, because a great deal of time would be required to remove the deep scratches made by the coarse grain. It would be better to follow the No. 36 with No. 60 and then use No. 120 grain if a finish as fine as this is required. Still finer grains could follow the No. 120 if necessary to produce the desired luster. When changing from one size to the next finer, some experts advocate changing the direction of the strokes, if practical, in order to facilitate the removal of scratches.

Glue

Too much emphasis cannot be placed on the proper selection and application of glue. Unsatisfactory glue conditions are actually responsible for most of the common troubles in the polishing room such as poor work, variable abrasive costs, irregular rate of production, difficulty in maintaining standard piece rates, and many other things of this nature.

In handling and preparing glue:

Store glue in a dry, cool place.
Measure glue and water by *weight.*
Use only cold water for soaking.
Use only distilled, boiled, or otherwise pure water.

While soaking, the glue should be completely covered with water.

Soak ground glue 3 hours, flake glue 8 hours, cake glue 12 hours.

Use only water-jacketed glue heaters.

Use aluminum glue pots.

Keep the glue pots covered.

Remove any scum that accumulates.

Stir glue while melting.

Temperature of the glue in the heater should not be over 140°F. A temperature higher than this will weaken the glue.

Never *boil* or *cook* glue.

Remember that bacteria spoil glue.

Use glue while fresh, preferably within four hours after heating.

Throw out any glue left at night.

Glue from the day before mixed with fresh glue weakens the mixture 50 per cent.

Scald pots and brushes every night.

Keep brushes not in use in a weak solution of carbolic acid.

Remove dead glue from floor, benches, tools, or wherever present.

Coarse grain requires thick glue while fine grain requires thin glue. For fine grain dilute the glue from the original mixture, according to "thinness" required.

Provide oven or preheating room for heating wheels before gluing up.

Heat wheels and abrasives to at least 120°F.

Allow plenty of time for glue to set, it does not attain its maximum strength in less than 48 hours.

SAND AND SHOT BLASTING

For cleaning castings and metal work, sand is used under air pressure. A sand that will pass through a No. 8 mesh screen is best for most purposes. Some work requires a very fine sand.

Air pressure varies from 2 to 5 pounds for frosting glass, to 80 and 90 pounds for heavy work.

Sand must be kept dry to prevent clogging nozzles. Pebbles are sometimes used with large nozzles to give a kind of peened finish. The operator should protect his nose and mouth with a wet sponge or respirator, and his hands with gloves.

With 25 to 30 pounds of air pressure a ½-inch nozzle will use about 200 pounds of sand an hour.

Sand of various grades and steel grit and shot are used. These are designated by the Pangborn Company by the letters *G* and *S* respectively. Centrifugal shot- and grit-throwing machines are replacing air in many cases, the abrasive being discharged at about the same velocity as when air is used. It is claimed that a centrifugal unit will discharge the same amount of abrasive as an air blast taking from ten to fifteen times as much power. Grit or shot varies widely in size, from 12 to 100 grit. They are frequently mixed for best results in cleaning. In centrifugal machines, a greater volume of shot than grit will flow through the feed. If grit is preferred, the addition of shot will increase the volume. With compressed air, the flow volume of shot is slightly greater than the grit and will do faster work in comparison to the volume.

BALL BURNISHING

Ball burnishing is a process employing a wood or wood-lined barrel with hard steel balls as burnishing medium and soapy water as lubricant. It forces down (not rubs off) by a half-rolling, half-rubbing pressure the minute irregularities that make the surface of metal parts appear unfinished, into a high luster and tends also to eliminate porosity. The wood lining of the barrel keeps the work from contacting the metal walls of the machine and prevents the revolving mass from rubbing off particles of metal and rust which would quickly form on the inside of the barrel above the burnishing solution when the cover was removed and cause discoloration of the work.

The basis of good burnishing is round steel balls. The factors to be considered are the speed of the machine; size or assortment of material; load in machine. The speed range depends mainly upon the diameter of barrel used. The smaller the barrel the higher the speed. A 24- or 30-inch machine requires about 15 revolutions per minute for a light burnishing action on delicate work and up to 45 revolutions per minute for work requiring a vigorous burnish. Within the limits, the faster the speed, the quicker the work is finished. Also much depends upon the size of material used. Small balls have more contacts with the surface but provide a light, very mild action. Large balls supply a far heavier burnishing effect and as they cost less per pound it is advisable to use as large a ball as practical.

From the hardness point of view it is usually possible to ball burnish any work whose surface is softer. To polish steel that is carburized or otherwise hardened, use balls with Vienna lime which sets up an extremely mild abrasive action and is very effective in a five to seven hour run.

The Abbott Ball Company recommends the use of two pecks of steel balls to every peck of work. To this is added enough water to stand about 1 inch above the work, and about 4 ounces of soap chips. It is preferable to dissolve the chips in hot water first. The rolling is carried on from 1 to 5 hours depending on the work.

The softer the metal the shorter the time required to finish it. If the work is not to be plated, it is taken directly from the barrel and dried in clean hardwood sawdust (preferably in a hot sawdust box), or, if it is of a nature to stand it, it can be placed in a tilting barrel with sawdust and tumbled a few minutes to dry.

If the work is to be plated it can be taken from the barrel and cleaned in the usual manner and, after plating, returned to the burnishing barrel with a fresh solution and the steel balls for the final finish, which requires about a half hour.

Approximate No. of Balls per Lb.

1/16 inch	27,900
3/32 inch	8,260
1/8 inch	3,125
5/32 inch	1,770
3/16 inch	1,024
1/4 inch	430
5/16 inch	220
3/8 inch	125
1/2 inch	52

There are about 100 pounds of steel balls in a peck.

IMPROVED CUTTING EDGES

The nearer perfect the edge of a cutting tool, the better the work it will do. This does not refer to the angle of the cutting edge with relation to the work, as both positive and negative cutting angles are now used. Perfection in this case refers to the removal of small irregularities left by the usual grinding wheel by using a very fine grit wheel and by stoning or honing. Careful attention to the cutting edge gives longer life between grinds and leaves a better surface on the work.

Extreme magnification of cutting edges shows great irregularities in the shape of hills and hollows created by the abrasive grains of the grinding wheels. An artist's sketch drawn from photomicrographs is shown in Fig. 13*a*. The largest projection, shown by the dotted lines, breaks off first. The others are shown at the right. These break because they are not strong enough to stand the heavy load imposed by the cut, leaving the whole cutting edge dull.

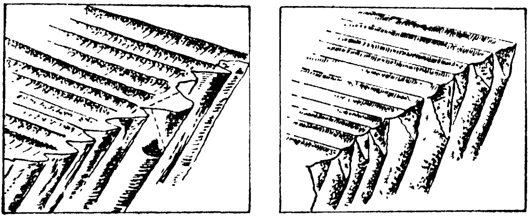

FIG. 13*a*.—*Left*, artist's conception of rough-ground cutting edges. Note the "hills" and "valleys" created by the abrasive grains of the grinding wheel in rough grinding. *Right*, note how the "peaks," unequal to the heavy load imposed upon them, break off, quickly dulling the cutting edge.

While no grinding or stoning can produce an absolutely perfect edge, the hills and hollows can be made so small that the cutting edge maintains its efficiency over a much longer period and produces much better surfaces. Frequently the improved surface left by the tool makes it possible to eliminate a grinding operation which was formerly necessary. This is particularly true in milling with negative rake cutters.

According to the Behr-Manning division of the Norton Company, good cutting can be secured with a 60-grit wheel with a very slow traverse and no feed on the last two passes. They consider it better, however, to grind first with a 60-grit wheel leaving 0.001 inch, or even less, for finishing with a 320-grit wheel with a shellac bond. Besides giving an excellent finish to the cutting edge, this method also impresses the operator with the importance of a cutting edge as perfect as possible and the great care necessary to secure it. With tools having carbide cutting edges many prefer to use diamond-impregnated wheels, particularly in milling and turning.

In both these machining operations it is advantageous to have the surface of the cutting tool very smooth to permit the chips to flow away from the work with as little resistance as possible. Blue chips, which are common in high-speed cutting of steel by either milling or turning, result from the heat generated in the chip itself by distorting the metal into a more or less tight curl. The more freely the chips slide over the tool face the less heat is generated and the less power is required. For this reason, some who have conducted extensive experiments along this line go to the extreme of stoning the face of the cutting tool *in the direction of chip flow.*

Cutting angles have much to do with the heat generated in chip removal. If we could use an acute cutting angle, as in woodworking tools, less power would be required and there would be fewer blue chips. But in order to secure the benefits of high cutting speeds made possible by using carbide tools, we must protect the edge by using a negative rake and, in many cases, a negative helix angle on face milling cutters. Cutting edges as perfect as possible increase cutter life here as elsewhere and improve the work surfaces. Cases are cited where the output per grind has been increased from 100 to 300 per cent.

In addition to the careful grinding of cutters, stoning or honing, immediately after sharpening and also at intervals before they require regrinding, has been found advantageous. It not only keeps the cutting edge in good condition but also lengthens the life of the cutter between grinds. Diamond-impregnated hones are now available for use with carbide cutters. This stoning removes any slight feather edge left by grinding. On high-speed steel cutters the India oilstone cuts faster than the Arkansas stone, but many prefer the latter on account of this slower action.

With carbide cutters, particularly those with a negative rake, some use the diamond hone directly on the edge, holding it at an angle of 45 degrees for one or two strokes. This not only removes the feather edge but produces a minute flat where the tool contacts the work.

OILSTONES AND THEIR USES

Natural Stones

The following particulars regarding the well-known Arkansas and Washita stones are given by the Pike Manufacturing Company:

Arkansas stones are made from rock quarried in the Ozark Mountains of Arkansas and are prepared for commercial purposes in two grades, hard and soft.

Hard Arkansas is composed of pure silica, and its sharpening qualities are due to small, sharp-pointed grains, or crystals, of hexagonal shape, which are much harder than steel and will, therefore, cut away and sharpen steel tools. The extreme fineness of texture makes this stone, of necessity, a slow cutter, but in the very density of the crystals of which it is composed lies its virtue as a sharpener.

Soft Arkansas stone is not quite so fine-grained and hard as the hard Arkansas, but it cuts faster and is better for some kinds of mechanical work. It is especially adapted for sharpening the tools used by wood carvers, filemakers, patternmakers, and all workers in hard wood.

Washita stone is also found in the Ozark Mountains in Arkansas and is similar to the Arkansas stone, being composed of nearly pure silica, but is much more porous. It is known as the best natural stone for sharpening carpenters' and general woodworkers' tools. This stone is found in various grades, from perfectly crystallized and porous grit to vitreous flint and hard sandstone. The sharpness of the grit depends entirely upon its crystallization, the best oilstones being made from very porous crystals.

In addition to the regular rectangular sections, natural stones are made in such shapes as square, triangular, round, flat, bevel, diamond, oval, pointed, knife edge.

Artificial Oilstones

Artificial oilstones are manufactured in a multitude of shapes and sizes and are adapted for sharpening all kinds of tools. Such stones are made of alundum and crystolon, by the Norton Company, the former being known as India oilstones, the latter as crystolon sharpening stones. Similar shapes are manufactured by the Carborundum Company and others.

The stones are made in three grades or grits—coarse, medium, and fine. The coarse stones are used in machine shops for sharpening very dull or nicked tools and machine knives and for general use where fast cutting is desired.

Medium stones are for sharpening mechanics' tools in general, more particularly those used by carpenters and in woodworking shops. Common shapes are shown in Fig. 14.

Fine stones are adapted for engravers, die workers, cabinet makers and other users of tools requiring a very fine, keen-cutting edge.

Of the great variety of shapes a number adapted especially for machine-shop purposes are illustrated. Of these, stones like No. 24 are for sharpening lathe and planer tools and for use after grinding; No. 23 is for reamers; No. 14, for taps; Nos. 4, 7, 10, and 26, for dies.

Two shapes for curved-edge woodworking tools are Nos. 10 and 14. A rectangular shape for straight-edge tools, like chisels, plane bits, planer knives, scrapers, paper-cutting knives, and other tools with broad flat edges is No. 24.

Some shapes suitable for die and tool work are shown by Nos. 4, 7, 26, 28 and 50. There are frequently several sizes in each shape.

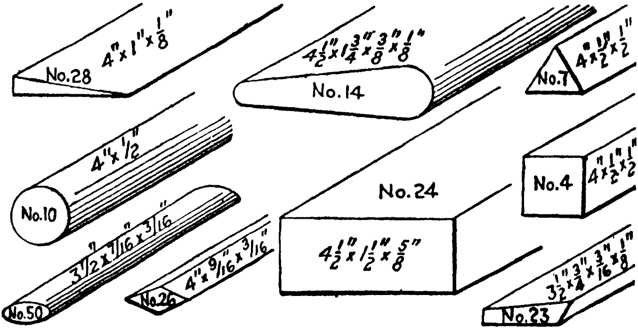

FIG. 14.—Oilstone Shapes

How to Care for Oilstones

Like anything else, an oilstone can be ruined by wrong treatment and lack of care.

There are three objects to be attained in taking good care of an oilstone: first, to retain the original life and sharpness of its grit; second, to keep its surface flat and even; third, to prevent its glazing.

To retain the original freshness of the stone, it should be kept clean and moist. To let an oilstone remain dry a long time or to expose it to the air tends to harden it. A new natural stone should be soaked in oil for several days before it is used. If an oilstone is kept in a dry place (most of them are) it should be kept in a box having a closed cover, and a few drops of fresh, clean oil should be left on the stone.

To keep the surface of an oilstone flat and even simply requires care in using it. Tools should be sharpened on the edge of a stone as well as in the middle, to prevent it from wearing down unevenly, and the stone should be turned end for end occasionally.

To restore an even, flat surface, grind the oilstone on the side of a grindstone or rub it down with sandstone or an emery brick.

An oilstone can be prevented from glazing merely by the use of oil or water.

Either oil or water is used on a sharpening stone to float the particles of steel that are cut away from the tool, thus preventing them from filling in between the crystals and causing the stone to glaze.

Water—and plenty of it—should be used on all coarse-grained natural stones.

On medium and fine-grained natural stones and in all artificial stones, oil should be used always, as water is not thick enough to keep the steel out of the pores.

Further to prevent glazing, the dirty oil should *always be wiped off the stone thoroughly* as soon as possible after using it. This is very important, for if left on the stone the oil dries in, carrying the steel dust with it. Cotton waste is one of the best things with which to clean a stone, and is nearly always to be found in a shop.

If the stone does become glazed or gummed up, a good cleaning with gasoline or ammonia will usually restore its cutting qualities, but if it does not, then scour the stone with loose emery or sandpaper fastened to a perfectly smooth board.

Never use turpentine on an oilstone for any purpose.

HONING

Honing Cylindrical Bores[1]

Grinding or honing of bores has now become general practice as a finishing operation. At first confined to automotive cylinders in which the grits, grades, and lengths of honing sticks would not exceed half a dozen sizes, today problems of grinding and honing cover several hundred styles of sticks and many grits and grades. Metal products made of cast iron, nickel iron, gun iron, malleable iron, aluminum, aluminum alloys, soft steels, hardened steels, nitrided steel, stellite, hot-drawn and cold-drawn tubes, yellow metals, including bronze and copper, are now honed in regular production.

Honing originally removed only the fuzz left from internal grinding wheels, broaches, reamers, or boring tools, this amount varying from 0.0002 to 0.003 inch. Honing now removes as much as $\frac{1}{64}$ inch from many bores, especially steel tubes and large engine bores, at the same time maintaining precision limits. It is sometimes found that bores distort from released stresses and are often egg shaped by several thousandths of an inch. This condition, however, does not prevent the bores being finished by honing to the precision limits required for concentricity and parallelism.

Steel tubes from $1\frac{3}{4}$ to 16 inches in diameter and in lengths to 60 feet are being honed, and compressors and heavy-oil engine cylinders over 30 inches in diameter are honed in regular production operations. Abrasive sticks have been so improved that the cost per bore can be satisfactorily controlled, and the truing of stones is no longer necessary.

Kerosene is the coolant generally used. It should be well filtered. On thin steel liners, airplane-engine cylinders, and similar work, 20 per cent of lard oil should be added to the kerosene. For honing tubes used in making food products use mineral seal oil, as it is tasteless, although it is somewhat sluggish in cutting qualities compared to kerosene. For aluminum alloys, Lynite, etc., lard oil gives the best results.

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[1] James G. Young and Frank J. Jeschke.

Honing requires much the same practice as in rotary wheel grinding. Suitable abrasive sticks must be selected for certain revolutions and reciprocating speeds per minute. It is often an advantage to vary the reciprocating speed especially in hardened materials, for when the fuzz is removed by the honing sticks the faces of the bores become harder and resist the cutting quality of the sticks. By variation in the speed of both revolutions and reciprocations, this resistance is overcome considerably and production times maintained.

Hones are of varying types but are mostly of the expanding segmental-wheel type, the grinding or honing surfaces being composed of a series of abrasive sticks placed longitudinally upon the circumference of a metal body with an adjusting means for expanding the stones (or sticks) to the walls of the cylinders being honed and holding them under pressure against the wall. The tool itself is rotated and reciprocated simultaneously, and the hones are now of the positive expanding type.

RECOMMENDED HONING SPEEDS

Bore, Inches	Revolutions per Minute	Traverse Speed in Feet per Minute
$1\frac{7}{8}$ to $2\frac{1}{4}$	185	45
$2\frac{1}{2}$ to 3	160	40
4 to $4\frac{7}{8}$	130	35
5 to $6\frac{1}{2}$	110	30
7 to $8\frac{1}{2}$	85	24
9 to 10	65	20

LAPPING

Lapping may be roughly defined as "precision finishing with abrasives." Specifically, it is the final stock-removing operation by means of which pieces of work are brought to desired size within closer tolerances for accuracy and with a finer finish than can be obtained by any other known mechanical process.

Hand Lapping

Hand lapping of flat pieces ordinarily performed by rubbing the parts to be lapped over the accurately finished flat surface of a master lap, the abrading action being accomplished by a very fine abrasive powder mixed with a lubricant. One principal characteristic of this operation is the movement of the work relative to the master lap. When properly performed, the piece is passed along an ever-changing path to ensure uniform abrasion of both the work and the lap and to eliminate, as far as possible, the production of parallel grain marks.

Lapping by means of this ever-changing path of abrasion, with its continual crisscrossing of these lines, results in what is known as a "matt" surface. It is not always a highly reflective surface, but the minute hills, or high spots, are removed, and what might be called "mountainous country" is reduced to "gently rolling" or "flat" country. Hand lapping is necessarily a slow, laborious operation and is not used except where expense and time are of minor consideration.

Laps are roughly divided into three general classes. First, those where the form of the lap makes a line contact with the work, and the work, if cylindrical, is revolved to develop the cylindrical form, or, if straight, in one direction, is moved back and forth under the lap. Second, those which are used for straight surfaces with a full contact on the lap, and third, those which are used for male and female cylindrical surfaces with a full contact on the lap. In all cases the material from which the lap is made must be softer than the work. If this is not so, the abrasive will charge the work and cut the lap, instead of the lap cutting the work.

The laps of the first class are usually made of machinery steel and the abrasive used is rolled into the surface. Oil is used to lubricate the work and carry away the dust.

Lapping Flat Surfaces

In lapping flat surfaces, which are usually on hardened steel, a cast-iron plate is used as a lap, with a good abrasive. In order that the plate may stay reasonably straight, it should either be quite thick or else ribbed sufficiently to make it rigid, and in any case it should be supported on three feet, the same as a surface place. For rough work or "blocking down," as it is called, the lap works better if scored with narrow grooves, about $\frac{1}{2}$ inch apart, both lengthwise and crosswise, thus dividing the plate into small squares, as in Fig. 15. The abrasive is sprinkled loosely on the block, wet with lard oil and the work rubbed on it; care is taken to press hardest on the highest spots. The abrasive and oil get in the grooves and are continually rolling in and out, getting between the plate and the work, and are crushed into the cast iron, thus charging it thoroughly in a short time. About No. 100 or 120 abrasive is best for this purpose.

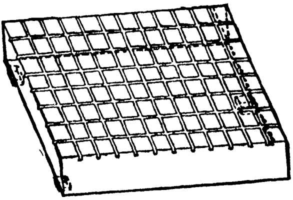

Fig. 15.—A Lapping Plate for Flat Work

After blocking down, or if the work has first been ground on a surface grinder, the process is different. A plain plate is used with the best quality of flour of emery as an abrasive, as the least lump or coarseness will scratch the work so that it will be very hard to get the scratches out. Instead of oil, benzine is used as a lubricant, and the lap should be cleaned off and fresh benzine and emery applied as often as it becomes sticky. The work should be tried from time to time with a straightedge and care taken not to let the emery run in and out from under the work, as this will cause the edges to abrade more than the center and will especially mar the corners. After getting a good surface, the plate and work should be cleaned perfectly dry and then rubbed. The charging in the plate will cut just enough to remove whatever emery may have become charged in the work, take away the dull surface and leave it as smooth as glass and as accurate as it is possible to produce.

Some grind flat work to within 0.0005 inch of size and lap to within 0.0002 inch on a type-metal lap charged with flour emery. The lap is used dry and cleaned with benzine. Crocus powder on a cast-iron lap gives a high polish.

In using the hand method on outside cylindrical surfaces, the work to be lapped is held in a chuck mounted on a lathe spindle and rotated, while the operator holds a split lap over the work surface by means of a clamp or holder. Loose abrasive grain is employed with a metal lap of cast iron, lead, brass, or other similar metal. Measurements are taken periodically to check the work diameter until it is lapped to the required size.

Laps for Holes

In lapping holes, various kinds of laps are used, according to the accuracy required, and the conditions under which the work is done. The simplest is a piece of wood turned cylindrical with a longitudinal groove or split in which the edge of a piece of emery cloth is inserted. This cloth is wound around the wood until it fills the hole in the work. This is only fit for smoothing or enlarging rough holes and usually leaves them more out of round and bell-mouthed than they were at first. Another lap used for the same purpose—and which produces better results—is made by turning a piece of copper, brass, or cast iron to fit the hole and splitting it longitudinally for some distance from the end. Loose abrasive is sprinkled over it, with lard oil for a lubricant, and a taper wedge is driven into the end for adjustment as the lap wears.

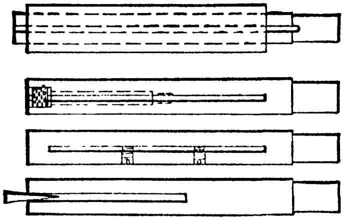

FIG. 16.—Laps for Holes

For lapping common drill bushings, cam rolls, etc., in large quantities, where a little bell-mouthing can be allowed, and yet a reasonably good hole is required, a great many shops use adjustable copper laps made with more care than the above. One way of making them is to split the lap nearly the whole length, but leaving both ends solid. One side is drilled and tapped for spreading screws for adjustment. Either one screw half-way down the split may be used or two screws dividing the split into thirds. Another and better means of adjustment is to drill a small longitudinal hole a little over half the length of the lap, enlarge it for half its length, and tap the large end for some distance. This is done before splitting. Into this hole a long screw with a taper point is fitted so that when tightened it tries to force itself into a small hole, thus spreading the lap.

For nice work there is nothing better than a lead lap. Lead charges easily, holds the abrasive firmly and does not scratch or score the work. It is easy to fit to the work and holds its shape well for light cuts. Under hard usage, however, it wears easily. For this reason, while laps for a single hole or a special job are sometimes cast on straight arbors, where much lapping is done it is customary to mold the laps to taper arbors with means for a slight adjustment. After any extensive adjustment the lap will be out of true and must be turned off. All of these laps, as shown in Fig. 16, are to be held by one end in a lathe chuck, and the work run back and forth on them by hand, or by means of a clamp held in the hand. If a clamp is used, care should be taken not to spring the work.

How to Do Good Lapping

There are several points which must be taken into consideration in order to get good results in lapping holes. The most important is that the lap shall always fill the hole. If this condition is not complied with the weight of the work and the impossibility of holding it exactly right will cause it to lap out of round, or if it is out of round at the start the lap will be free to follow the original surface. If the lap fits, it will bear hardest on the high spots and lap them off. Next in importance to getting a round hole is to have it straight. To attain this end the lap should be a little longer than the work, so that it will lap the whole length of the hole at once, and not have a tendency to follow any curvature there may be in it. What is known as bell-mouthing, or lapping large on the ends, is hard to prevent, especially if the emery is sprinkled on the lap and the work shoved on it while it is running. The best way to avoid this condition when using cast-iron or copper laps, which do not charge easily, is to put the abrasive in the slot, near the center of the lap, and after the work is shoved on squirt oil in the slot to float the abrasive. Then, when the lathe is started the abrasive will carry around and gradually work out to the ends, lapping as it goes. Where lead is used, the abrasive can be put on where it is desired to have the lap cut and rolled in with a flat strip of iron. It will not come out easily, so will not spread to any extent, and it is possible with a lap charged in this manner to avoid cutting the ends of the hole at all. The work should always be kept in motion back and forth to avoid lumping of the abrasive and cuttings which will score grooves in the work.

Ring Gage and Other Work

Ring gages are lapped with a lead lap. They are first ground straight and smooth to within 0.0005 inch of size, and then, when lapped, are cooled as well as cleaned, before trying the plug, by placing them in a pail of benzine for a long enough time to bring them down to the temperature of the room. Some shops leave a thin collar projection from each side around the hole, so that, if there is any bell mouthing, it will be in these collars, which are ground off after the lapping is done.

Soft metals and cast iron will charge. To some extent charging can be taken out without changing the work materially by rubbing it by hand with "flour" abrasive cloth. In lapping bronze or brass, crocus and Vienna lime are used. Crocus is used with a cast-iron or lead lap, and the charging is removed by running the work for a few seconds on a hardwood stick which fits the hole. Unslaked Vienna lime, freshly crushed, is used with a lead or hardwood lap, and does not charge. It does a nice job, but is very slow, and is used only in watch factories.

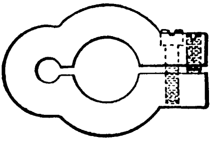

FIG. 17.—A Lap for Plugs

For lapping plug gages, pistons, and other cylindrical articles, a cast-iron lap is usually used, split and fitted with a closing and a spreading screw, as shown in Fig. 17. Sometimes, where a very fine finish is required, or where the work is not hardened, the hole is made larger than the work, and a lead ring cast into it.

Adjustable Step Lap for Plug Gages

The step lap, Fig. 18, can be used to advantage for plug gages. It is of gray cast iron, and the end hole *A* adjusted to size. The lap is used at this hole until it refuses to cut. The plug gage is then entered into hole *B* without changing the adjustment. This hole is used up, and the plug gage is passed to holes *C* and *D*.

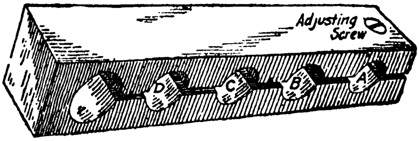

FIG. 18.—Step Lap for Plug Gages

As the holes are all made one size and as the plug gage becomes smaller at each hole, there is less wear on the lap as the plug is passed from hole to hole. The holes retain about the same proportions and save measuring for sizes very often, when rough-lapping the plugs to within 0.0001 inch of finish size. As a finishing lap for size, it requires very few trial measurements with the micrometer or ring gage.

There is a tendency among workmen to use an excessive rotary speed when lapping a plug or ring. A speed that will make the work just comfortably warm to the hand is about right. Speed above this rate has a tendency to bake the oil and abrasive, which is a detriment to smooth and fast cutting.

Diamond Powder in the Machine Shop

The diamond used for this purpose is an inferior grade of diamond, not so hard as the black diamond used for drills and truing emery wheels, and not of the clear and perfect structure to permit it to enter the gem class. Many are mixed black and white, others yellow and some pink; many are clear but flaky. Then there is the small débris from diamond cutting, which is reduced to powder and sells somewhat cheaper; but some find it more economical to use the above and powder it themselves, as the débris from diamond cutting is of a flaky nature, and does not charge into the lap so well.

Assuming there is 25 carats to reduce to powder, proceed as follows:

Into a mortar, as shown at Fig. 19, place about 5 carats, using an 8-ounce hammer to crush it. It takes from 3 to 4 minutes' steady pounding to reduce it to a good average. Scrape the powder free from the bottom and the sides and empty into one-half pint of oil. The oil used is the best olive oil obtainable, and is held in a cup-shaped receptacle that will hold a pint and one half. The 25 carats being reduced to powder, and in the oil, stir it until thoroughly mixed, and allow to stand 5 minutes; then pour off to another dish. The diamond that remains in the dish is coarse and should be washed in benzine and allowed to dry, and should be repounded, unless extremely coarse diamond is desired. In that case label it No. 0. Now stir that which has been poured from No. 0, and allow to stand 10 minutes. Then pour off into another dish. The residue will be No. 1. Repeat the operation, following the table below.

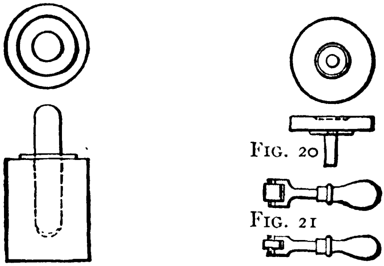

FIG. 19 FIG. 20 FIG. 21 FIG. 22

FIGS. 19–22.—Tools for Preparing Surface Lap

The settlings can be put into small dishes for convenient use, enough oil staying with the diamond to give it the consistency of paste. The dishes can be obtained from a jewelers' supply house.

TABLE FOR SETTLING DIAMOND POWDER

To obtain No. 0— 5 minutes.
To obtain No. 1—10 minutes.
To obtain No. 2—30 minutes.
To obtain No. 3—1 hour.
To obtain No. 4—2 hours.
To obtain No. 5—10 hours.
To obtain No. 6—until oil is clear.

Diamond is seldom hammered; it is generally rolled into the metal. For instance, several pieces of wire of various diameters charged with diamond may be desired for use in die work. Place the wire and a small portion of the diamond between two hardened surfaces, and under pressure roll them back and forth until thoroughly charged. In this case No. 2 diamond is generally used. Or one can form the metal to any desired shape and apply the diamond and use a roll, as Fig. 21, to force the diamond into the metal. This is then a file which will work hard steel, but the moment this diamond file, or lap, is crowded, it is stripped of the diamond and is consequently of no use. It is to be used with comparatively light pressure.

Diamond Laps

Copper is the best metal. It takes the diamond readily, and retains it longer than other metals; brass next, then bessemer steel. The latter is used when it is wished to preserve a form that is often used.

For sharpening small, flat drills, say 0.008 to 0.100, a copper lap mounted on a taper shank, as in Fig. 20, and charged on the face with No. 2 diamond, using pressure on the roll, makes a most satisfactory method of sharpening drills. The diamond lasts for a long time if properly used, and there is no danger of drawing the temper on the drill. It is much quicker than any other method of sharpening.

To charge the lap use the roll, Fig. 21, supported on a T-rest pressing firmly against the lap, being careful to have the roll on the center; otherwise, instead of charging the lap, it will be grinding the roll. The diamond may be spread on either the lap or the roll, and the first charging usually takes twice the amount of diamond that subsequently charging takes. To avoid loss of diamond, wash the lap in a dish of benzene kept exclusively for that purpose. This can be reclaimed by burning the metal with acids, and the diamond can be resettled. A narrower roll, Fig. 22, is sometimes used.

For the grinding of taper holes in hard spindles or for position work in hard plates, where holes are too small to allow the use of wheels, No. 1 diamond works well. To grind sapphire centers or plugs as stops, use a bessemer lap made in the form of a wheel charged with diamond on the outside.

Numbers 5 and 6 diamond are used on boxwood laps, mounted on taper plugs or chucks, and the diamond smeared on with the finger. The lap is run at high speed and used for fine and slow cutting which also gives a high polish.

Other Abrasives for Lapping

The abrasive flours commonly used for lapping have a grain averaging about 0.002 inch in diameter. For fine work, the abrasive flours are mixed with oil and allowed to settle. The lighter particles remain in suspension and are poured off. They are graded according to the length of time they float: thus, 30-minute abrasive means the particles have taken 30 minutes to settle. Some use water for floating, as oils vary so much in viscosity. The most used lapping lubricants are lard oil, machine oil, kerosene, gasoline, alcohol, and turpentine.

The ideal abrasive for lapping is one which will break down or become finer as work goes on.

Tests of Lapping

Tests made by Knight and Case show that laps charged by rolling cut the fastest and that a lap wet with lubricant cuts approximately twice as fast as a dry lap. The initial rate of cutting does not vary greatly with different abrasives. No advantage was found in using an abrasive coarser than No. 150. The rate of cutting is practically proportional to the pressure, 15 pounds being satisfactory. Laps wear as follows: Cast iron, 1.00; steel, 1.27; and copper, 2.62. In general, copper and steel cut faster than cast iron, but cast iron retains its form better.

Good Lapping Combinations

Silicon Carbide —Steel lap —Lard oil
Silicon Carbide —Copper lap—Lard oil
Silicon Carbide —Cast lap —Gasoline
Aluminum Oxide—Copper lap—Soda water
Silicon Carbide —Cast lap —Turpentine
Silicon Carbide —Cast lap —Alcohol
Aluminum Oxide—Cast lap —Gasoline
Silicon Carbide —Copper lap—Turpentine
Silicon Carbide —Cast lap —Kerosene
Silicon Carbide —Copper lap—Soda water
Silicon Carbide —Steel lap —Machine oil
Aluminum Oxide—Copper lap—Turpentine
Silicon Carbide —Copper lap—Machine oil
Aluminum Oxide—Copper lap—Alcohol
Silicon Carbide —Copper lap—Alcohol

Machine Lapping

Modern lapping machines have made possible the quantity production of parts, the cost of which would have been prohibitive by the old hand-lapping methods.

Industrial requirements demand lapping machines arranged to use three types of lapping mediums. One uses metal laps and loose abrasive grain mixed with a lubricant and will always find a place in the field of gage manufacture, or for other operations where extreme accuracy is required.

Another type of machine uses bonded abrasives for commercial production work.

A third and more recent type of machine, which at present has been used for crankshaft lapping exclusively, employs abrasive paper or cloth instead of cast-iron or bonded abrasive sticks. A very bright finish is obtained and a genuine lapped surface is produced quite as easily as with cast-iron or bonded abrasives.

Vertical machines with cast-iron laps using loose abrasive are used for cylindrical work, flat work, and there is a universal type for both flat and cylindrical work. Vertical machines with bonded abrasive laps are made for both cylindrical and flat work. Horizontal machines use abrasive paper or cloth, as in the crankshaft machine.

Work holders for vertical machines differ widely, the simplest form consisting of a circular disc perforated with holes near its periphery. These holes are of such size that the work can be laid in them as the work holder rests in position on the machine. Sufficient clearance between the pieces and the work holder is provided so that the only effect the work holder has on the work is to move it about between the laps.

When the work holder is arranged for cylindrical pieces, which do not have a hole through them, these openings are of the approximate shape of the piece. The axis of the opening is not radial, but tangent to a circle approximately 3 inches in diameter concentric with the center of the work holder.

For lapping cylindrical pieces, such as piston pins, which have a hole through the center, a leg or spider-type work holder is used. This consists of an aluminum center plate with hardened-steel spindles inserted about its periphery. As in the case of the flat- or plate-work holder for cylindrical pieces, these spindles are not placed radially but have their axes tangent to a circle about 3 inches in diameter.

Preparation of Parts for Lapping

From a production standpoint lapping is not a stock removal operation. In no case should more than 0.0005-inch material be left for the lapping operation. Lapping is not intended to replace grinding, but further to refine pieces beyond that point of finish and accuracy produced by the grinding operation.

Parts should always be ground to close limits for size, parallelism, roundness, or flatness before lapping, although the ground finish is not so important.

Lapping Lubricants

With machines equipped with cast-iron laps, lard oil and kerosene mixed with the proper abrasive to form a paste is the only lubricant required. For final-finish lapping operations and when finish dressing the laps, the paste is omitted, and plain kerosene only is used.

Superfinish

Superfinish is a method developed by David A. Wallace, president of the Chrysler division of the Chrysler Corporation, to secure the best known surface on wearing parts. The machines give a combination of motions to the abrasive materials, mostly at right angles to the work. Only one movement, and that at low velocity, is in the direction of the tooling marks. The oscillating movements are quite rapid, but the actual surface speed is only 12 to 15 feet per minute because of the narrow range of the stone oscillations.

Only enough pressure is used so that the high spots will puncture the film of light oil and be honed down. Increasing the pressure makes more high spots break through the oil film until the surface is so smooth that the film is no longer punctured.

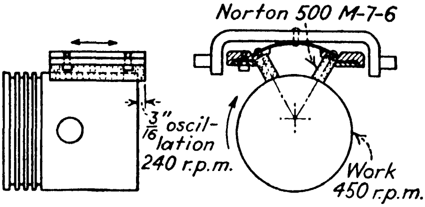

FIG. 23.—Superfinishing Piston

This method is for finish only, not for correcting dimensions. Chrysler prefers a medium rough ground surface to a smooth grind, before superfinishing. For example, brake drums are turned with a feed of 0.022 inch, which saves turning time. When superfinished, the deepest mark is but 0.00001 inch deep. Commercial stones are used, care being taken to get uniform grain size. These are secured by the settling or float process. While extreme accuracy is secured, smoothness to the millionth of an inch being obtainable, the operation takes but from 3 to 30 seconds.

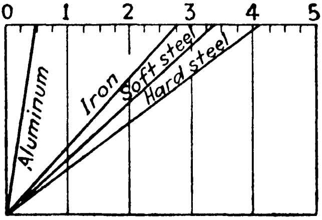

FIG. 24.—Ratios of Reciprocations per Minute to Revolutions per Minute

The method of superfinishing a piston is shown in Fig. 23, which gives all necessary information. Figure 24 shows the best ratios of reciprocation to work revolutions for different materials. Hard material requires more reciprocation in proportion to rotation. There must be at least three motions to give the best results.

Superfinish shows remarkable results in increasing the wear life of metals in contact. It bears out the statement of the Bureau of Standards some years ago that smoothness of finish had more effect than hardness on the wear of gages.

Surface Finish.—The growing use of the Profilometer to measure the quality of surface finish makes it desirable to understand the terms used. The depth of scratches is measured in microinches, or *millionths* of an inch. Readings are often expressed as 5 r.m.s. The letters mean root-mean-square, but in shop language, the average variation from a center line. In other words a line half-way between the peaks and valleys of a profile of the surface.

GRINDING SPRAYED METAL

Where grinding equipment is available, it is being used more extensively to finish sprayed metal than are cutting tools. This is

CYLINDRICAL GRINDING—WET

Metal	Abrasive Type	Abrasive Grit Size	Abrasive Grade	Bond
Sprabronze C:*				
Rough and finish..	Si-carbide	36 to 120	Soft or med.	Vitrified
Lustrous finish...	Si-carbide	80 to 120	Soft or med.	Vitrified
Sprabronze M:				
Rough and finish..	Si-carbide	36 to 46	Soft or med.	Vitrified
Lustrous finish....	Si-carbide	60 to 80	Soft	Vitrified
Sprabronze T:				
Rough and finish..	Si-carbide	36 to 46	Soft or med.	Vitrified
Lustrous finish....	Si-carbide	60 to 80	Soft	Vitrified
Copper:				
Rough and finish..	Si-carbide	36 to 46	Soft or med.	Vitrified
Lustrous finish	Si-carbide	60 to 80	Soft	Vitrified
Monel:				
Rough and finish .	Si-carbide	46 to 60	Soft or med.	Vitrified
Lustrous finish....	Si-carbide	60 to 80	Soft	Vitrified
Nickel:				
Rough and finish .	Si-carbide	46 to 60	Soft or med.	Vitrified
Lustrous finish ...	Si-carbide	60 to 80	Soft	Vitrified
Metcoloy No. 1:				
Rough and finish..	Si-carbide	46	Soft	Vitrified
	Al-oxide	400	Medium	Vitrified
Metcoloy No. 2:				
Rough and finish..	Si-carbide	36 to 46	Soft or med.	Vitrified
Sprasteels 10, 25, 40, 80 and 120:				
Rough and finish..	Si-carbide	36 to 46	Soft or med.	Vitrified

* Slow traverse (approximately ½ ft. per min.) and high work speed (approximately 140 surface ft. per min.) are absolutely essential in grinding Sprabronze C. High traverse rates cause the wheel to load badly and give a poor finish.

NOTES:

Wheel speeds, surface ft. per min.................	6,000 to 6,500
Work speed, surface ft. per min..................	80 to 90
Traverse speed, roughing, in. per min.............	36 to 48
Traverse speed, finishing, in. per min.............	8 to 16
Infeed:	
Roughing in................................	0.001
Finishing................................	Extremely light

Coolant most generally used is 50:1 to 40:1 soluble oil.

true of soft metals such as Metcoloy No. 1 and Metco copper. It permits greater accuracy and a higher degree of finish than can be obtained by cutting tools.

Sprayed metals require a different procedure than parent, or solid, metal of the same composition. They can be ground wet or dry by following the suggestions in the tables herewith. These show the wheel speeds and work feeds and the type of wheels for the different metals, and they suggest coolants that give good results. Sprayed metals tend to load grinding wheels. Relatively coarse grain and low bond strength are necessary to permit the wheels surface to break down easily.

Tool-post grinders may require different wheels than grinders with more rigidly supported wheels. They can be used, however, by experimenting to find the right wheel for the grinder and the work.

CRUSH-DRESSING GRINDING WHEELS[1]

The accepted method of dressing or preparing the abrasive-wheel surface for work has been by the use of sharp diamonds, or other hard material such as the carbides, usually termed "diamond-dressing." Equally old is the process of dressing a wheel by means of a number of freely rotating washers mounted on a suitable handle. This tool is normally used for roughing up pedestal abrasive wheels, and grit can be removed from the face of the wheel very rapidly. From this it is a short step to modern "crush-dressing." This principle for the accurate dressing of grinding wheels has been undergoing improvements in Europe, and it has been receiving specialized development in the United States.

Crushing of abrasive wheels may seem revolutionary to some, as the method has not had widespread industrial application in America. Since its general commercial introduction in this country, rapid progress has been made as industry has come to realize the advantages. Abroad, the development has been primarily used in the grinding of threads, owing largely to the European and English practice of grinding threads with multiribbed wheels. The benefits of this method are so outstanding, it is not surprising that great strides have been made in multiforming the ribs of grinding wheels. Various and often complicated fixtures were used for diamond dressing of these wheels, and, while searching for a simpler operation, the crushing technique was developed. While it was primarily intended to simplify the fixtures for forming the wheel, advantages were discovered that are far more important than the simplification.

For a number of years several enterprising toolrooms in the United States used the crushing technique with excellent results. For example, one company found it profitable to make lamination-die sections on the surface grinder after first crushing a wheel to the desired shape by means of a soft-steel crusher mounted on a fixture. This fixture allowed free rotation without end movement. The

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Cylindrical Grinding—Dry*

Metals	Surface Speed, Ft. per Min.		Feed, In. per Rev.	
	Work	Wheel	Roughing	Finishing
Sprabronze C†	40 to 45	5,000 to 6,000	$\frac{1}{16}$ to $\frac{1}{8}$	$\frac{1}{64}$ to $\frac{1}{32}$
Sprabronze M†	40 to 45	5,000 to 6,000	$\frac{1}{16}$ to $\frac{1}{8}$	$\frac{1}{32}$ to $\frac{3}{64}$
Sprabronze T†	30 to 40	5,000 to 6,000	$\frac{1}{16}$ to $\frac{1}{8}$	$\frac{1}{32}$ to $\frac{3}{64}$
Copper†	30 to 40	5,000 to 6,000	$\frac{1}{16}$ to $\frac{1}{8}$	$\frac{1}{32}$ to $\frac{3}{64}$
Monel†	30 to 40	5,000 to 6,000	$\frac{1}{64}$ to $\frac{1}{16}$	$\frac{1}{128}$ to $\frac{1}{32}$
Nickel	30 to 40	5,000 to 6,000	$\frac{1}{64}$ to $\frac{1}{16}$	$\frac{1}{128}$ to $\frac{1}{32}$
Sprairon	30 to 40	5,000 to 6,000	$\frac{1}{16}$ to $\frac{1}{8}$	$\frac{1}{32}$ to $\frac{3}{64}$
Metcoloy No. 1	30 to 45	5,000 to 6,000	$\frac{1}{32}$ to $\frac{1}{16}$	$\frac{1}{32}$ to $\frac{3}{64}$
Metcoloy No. 2	45 to 125	5,000 to 6,000	$\frac{1}{64}$ to $\frac{1}{16}$	$\frac{1}{128}$ to $\frac{1}{32}$
Sprasteels 10, 25	30 to 45	5,000 to 6,000	$\frac{1}{16}$ to $\frac{1}{8}$	$\frac{1}{32}$ to $\frac{3}{64}$
Sprasteel 40	30 to 45	5,000 to 6,000	$\frac{1}{16}$ to $\frac{1}{8}$	$\frac{1}{32}$ to $\frac{3}{64}$
Sprasteel 80	30 to 45	5,000 to 6,000	$\frac{1}{16}$ to $\frac{1}{8}$	$\frac{1}{32}$ to $\frac{3}{64}$
Sprasteel 120	30 to 45	5,000 to 6,000	$\frac{1}{16}$	$\frac{1}{64}$ to $\frac{1}{32}$

* For the first six metals listed use silicon-carbide wheels, vitrified bond, of No. 60 soft abrasive. For the last eight, use silicon-carbide wheels, vitrified bond, No. 46 grit, very soft grade.

† It may be necessary with these metals to apply a light coat of machine oil after each cut to keep the wheel from loading.

Notes: Frequent dressing of the wheel when finish grinding Sprabronze and copper will promote faster cutting if more than one piece is to be ground, because of the loading that takes place on the wheel face from this type of material.

Recommended infeed per pass for rough grinding is 0.001 in. Use extremely light infeed for finishing.

wheel was run down against the crusher, and a crank was used to turn the wheel slowly and impress the form in its surface.

Technique of Crush-Dressing

Roughly speaking, the present technique of crush dressing an abrasive wheel is as follows: A crusher is made similar to a circular form tool, carrying the identical shape to be ground in the work piece. This crusher is usually mounted on antifriction bearings that will allow no end play. It is placed in a suitable fixture which, in turn, is attached to the machine by a method depending upon the type of installation and permits the crusher to be slowly moved toward the wheel or the wheel toward the crusher. The axis of rotation of the crusher should be parallel to the axis of rotation of the grinding wheel for best results.

The peripheral speed should be approximately 250 to 300 feet per minute. While rotating, the axes of the two are slowly brought together with the result that grit is removed from the wheel.

Crush-Dressing Has Many Advantages

As previously mentioned, in the development of crush-dressing a number of advantages were found to be of greater importance than the simplification. They may be listed as follows:

1. On the most varied of profiles, crush-dressing forms the wheel to the desired shape in a fraction of the time possible by any of the previous conventional dressing methods.
2. Crush-dressing provides a better cutting surface with many more sharp cutting points and without the dull flats produced by diamong-dressing.
3. The number of pieces that may be ground per dressing is remarkably increased.
4. The cost of dressing tools is greatly reduced, not only because of the number of pieces ground per dressing, but also because of the tremendous number of dressings possible with the crusher-dressed tools. Although still having some limitations, this is the modern inexpensive way of dressing a grinding wheel and getting the most intricate of shapes.
5. Longer wheel life is obtained by crusher-forming because it is only necessary to remove the dulled grits. The dressing operation itself does not tend to dull the grits as in diamond-dressing.
6. Crush-dressing allows closer grinding of work and reduces the hazard of burning. Less pressure is necessary to remove stock.

SECTION XII

SCREW-MACHINE TOOLS, SPEEDS, AND FEEDS

Box tools are the most commonly used of all screw-machine tools, whether on hand or automatic machines. This is because they can be used for roughing or finishing cuts on straight turning or several tools can be used in the one holder and a series of diameters turned at once. Or a centering tool, or a drill, or some facing tool can be set in the shank and still another operation thus accomplished with the original box tool. The cutters or bits employed admit of a variety of arrangements.

Although the box tool is useful as a roughing tool, it is more generally employed in modern practice for finishing cuts, the roughing being more commonly done with such a tool as a hollow mill, which is usually made to turn from 0.006 to 0.012 inch oversize.

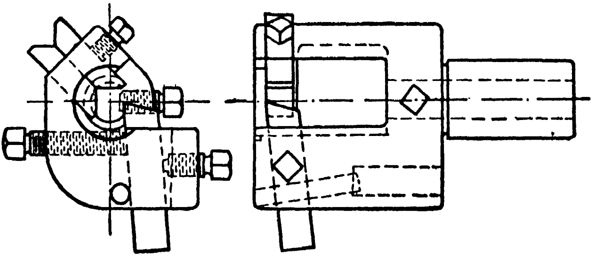


FIG. 1.—Tangent Box Tool

The box tool with tangent form of cutter and adjustable back rests is shown in Fig. 1. The cutter or bit is slightly in the lead of the back rests and cuts to size so that the work enters the rests and is supported therein for the entire length of the cut.

If two cutters are to be used in the box tool, the box is slotted out to proper width. Each tool is independently adjustable, and in some types the cutters are carried in separate blocks adjustable along the length of the box toolholder. Roller back rests are also used in some cases.

In Fig. 2, the edge of the cutter is over the center of the work, and the angular, or side, clearance *a* is usually 8 or 10 degrees. The face *b* is ground back to give a good cutting effect at an angle *c* of 15 to 40 degrees depending upon material, etc. The angle *d* may be from 0 to 15 degrees or more according to conditions.

HOLLOW MILLS

The hollow mill so commonly used on hand and automatic screw machines is particularly useful for roughing cuts and ordinarily for such purposes is made to turn the work to within 0.006 or 0.008 inch above size for diameters up to $\frac{1}{4}$ inch. For sizes above that, up to about $\frac{11}{16}$ inch, an allowance commonly left by the hollow mill for finishing by box tools or otherwise is 0.010 to 0.012 inch.

The hole *a*, Fig. 3, is ground taper to provide clearance and prevent drag at the back of the mill. The taper usually ranges from 0.006 to 0.015 inch large at the back end of the hole according to the size of the mill.

Hollow mills are made with the cutting edge of the teeth tangent, or parallel, to the radial line through the center, the amount *d* the cutting edge is ahead of center varying with the diameter of the hole in the mill. The amount ahead of center is somewhat greater than in early practice as Brown & Sharpe Mfg. Co. recommend $\frac{1}{6}$ of the diameter for mills up to $\frac{1}{4}$ inch and $\frac{1}{4}$ of the diameter for larger mills, up to $\frac{11}{16}$ in. This refers to hollow mills for turning steel For brass the teeth should be ahead of the center approximately 0.010 to 0.015 inch.

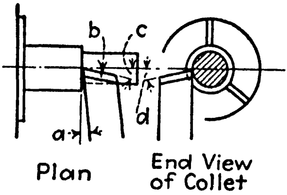


FIG. 2.—The Cutting Tool

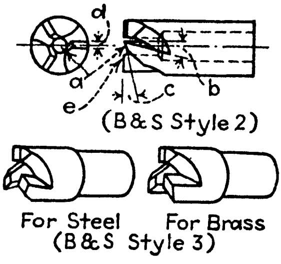


FIG. 3.—Hollow Mills

By referring to Fig. 3 and Table 1, it will be seen that as the mills are ground, the rake *b* causes the cutting edge to move back toward the center with each grinding. With too small allowance ahead of center, the mill is used back too rapidly, as its useful cutting life is practically limited to the point where it reaches the center line.

Two styles of Brown and Sharpe mills are shown in Fig. 3; one with plain body (style 2) and one with enlarged head (style 3). The hollow mill for brass is made with straight lip instead of with the top rake *b*.

Table 1 gives essential details of hollow mills for different sizes of Brown and Sharpe automatics and wire feed machines. The top rake *b* for the teeth is usually at an angle of about 16 degrees for cutting steel. For brass this angle is zero, the top or face of the tooth being parallel with the centerline. The clearance angle *c* at the end of the tooth should be from 12 to 15 degrees. Where feasible, it is desirable to bevel off the inner corners of the teeth at *e* to an angle of 45 degrees. This helps to guide the hollow mill and give a free cutting action.

TABLE 1.—HOLLOW-MILL PROPORTIONS
Brown and Sharpe Screw Machines

No. of Mill	Style	No. of Machine, Where Used	Regular Sizes	Diameter of Shank	Length of Shank	Diameter of Head	Length of Head	Total Length
00C*	2	00, 00G and 19 Auto.	1/16 to 7/32 by sixty-fourths	No. 5 Taper		1/2		1 1/8
00D	2					1/2		1 1/8
20A	3	0 and 0G Auto 1 W.F.	1/8 to 5/16 by sixty-fourths	5/8	7/8	3/4	7/8	1 3/4
20B†	3	0 and 0G Auto 1 W.F.	1/8 to 3/8 by thirty-seconds	5/8	7/8	3/4	7/8	1 3/4
21A	2	1 Auto	1/8 to 3/8 by thirty-seconds	3/4		3/4		2
22A	2	2 and 2G Auto 2 and 2F W.F.	1/4 to 7/16 by thirty-seconds	1		1		2 1/4
22C	3	3 and 2G Auto 2 and 2F W.F.	15/32 to 11/16 by thirty-seconds	1	1 3/16	1 1/4	1 1/16	2 1/4

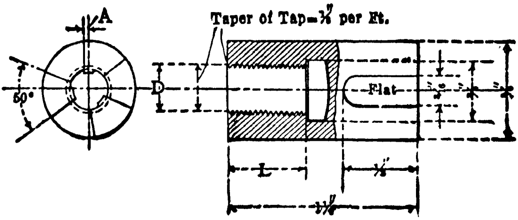
NOTE.—Style 2 mill is made with a straight body. Style 3 has reduced shank as dimensioned in above table.
* Made in both right- and left-hand styles.
† For brass.

DIES AND TAPS

It is good practice in making spring-screw dies either to hob out the thread with a hob tap 0.005 to 0.015 inch oversize, according to size, and in use to spring the prongs to proper cutting size by a clamping ring, or to tap the die out from the rear with a hob tap tapering from 3/16 inch to 1/4 inch per foot, leaving the front end about 0.002 inch over cutting size, and in this case also to use a clamping ring. Both of these schemes are for the purpose of obtaining back clearance and are effective. Of the two, the use of the taper hob is to be preferred.

Spring-Die Sizes

The dimensions for spring-screw dies, with Fig. 4, should prove of service, particularly for steel. For brass the cutting edge is radial, thus eliminating dimension *A*. The width of land at bottom of thread is usually made about one-fourth outside diameter of cut, the milling between flutes being 70 degrees, leaving 50 degrees for the prong in the case of three-flute dies.



SMALL SIZES OF DIES
(Overall Dimensions Given in Sketch)

D =	1/16	1/8	3/16	1/4	5/16	No. 3	4	6	8	10	12
Threads P. I. =	64	40	32	20	18	56	40	32	24–32	24–32	24–32
$A = \frac{D}{10}$	.006	.012	.019	.025	.031	.010	.011	.014	.016	.019	.021
L =	3/16	9/32	3/8	1/2	1/2	7/32	1/4	9/32	5/16	11/32	3/8

SIZES 3/8 TO 1 INCH

D =	3/8 to 1/2	1/2 to 3/4	3/4 to 1
Threads P. I. =	Std.	Std.	Std.
A =	D ÷ 10	D ÷ 10	D ÷ 10
L =	3/4	1"	1 1/2
O.S. Dia.	1"	1 1/4	1 5/8
Length	2"	2 1/4"	2 1/2"

FIG. 4.—Spring-Die Sizes

Boring Work for Threading

When holes are bored previous to tapping, they should be somewhat larger than the theoretical diameter at bottom of thread, as the crowding action of the tap will cause the metal to flow some and compensate for this. Where no allowance is made, frequent tap breakage is liable to occur, as well as torn threads in the work. On external work it is advisable for the same reasons to turn the work undersize, and Table 2 gives good average allowances for internal and external work.

TABLE 2.—ALLOWANCES FOR THREADING IN THE SCREW MACHINE

Threads per Inch	External Work Turn Undersize	Internal Work Increase Over Theoretical Bottom of Thread
28	0.002	0.004
24	0.002	0.0045
22	0.0025	0.005
20	0.0025	0.0055
16	0.003	0.006
14	0.003	0.0065
13	0.0035	0.007
12	0.0035	0.007
11	0.0035	0.0075
10	0.004	0.008
9	0.004	0.0085
8	0.0045	0.009
7	0.0045	0.0095
6	0.005	0.010

Tap Length and Number of Lands

The number of teeth in taps and the width of land should be regulated by the diameter and pitch of work as well as the nature of the material being cut. On fine threads, where a shrunken thread is to be ensured against, more teeth are required than on a coarser pitch of the same diameter. A good average number of teeth on taps for American standard threads is given in the following table.

Outside Diameter	No. of Flutes	Width of Land
$\frac{3}{16}$	4	$\frac{3}{64}$
$\frac{1}{4}$	4	$\frac{1}{16}$
$\frac{5}{16}$	4	$\frac{5}{64}$
$\frac{3}{8}$	4	$\frac{3}{32}$
$\frac{7}{16}$	4	$\frac{7}{64}$
$\frac{1}{2}$	4	$\frac{1}{8}$
$\frac{5}{8}$	4	$\frac{5}{32}$
$\frac{3}{4}$	4	$\frac{3}{16}$
$\frac{7}{8}$	4	$\frac{7}{32}$
1	4	$\frac{1}{4}$
1 $\frac{1}{4}$	4	$\frac{5}{16}$

With too few teeth and too short land, very little support is available, and this may cause chattering; too much land in contact causes heat, may cause excessive friction, welding of chips, and torn threads.

FORMING TOOLS

The two types of forming cutters commonly used in the screw machine are shown in Figs. 5 and 6. The circular forming cutter in Fig. 5 is usually cut away from $\frac{1}{8}$ to $\frac{3}{16}$ inch below center to give suitable cutting clearance, and the center of the tool post on which it is mounted is a corresponding amount above the center of the machine, so that the cutting edge of the circular tool is brought on the center line of the work. The relative clearance ordinarily obtained by circular cutters and dovetail tools of the type shown in Fig. 6 is indicated in Fig. 7. It is obvious that with a given material the larger the diameter of the work, the greater the angle of clearance required. Clearance angles are seldom less than 7 degrees or over 12 degrees. The diagram with Fig. 6 shows why form tool contours must vary with the clearance angle.

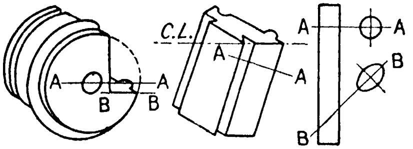


FIG. 5 FIG. 6

FIGS. 5 and 6.—Circular and Dovetail Form Tools

The diameter of circular forming tools is an important matter for consideration. A small diameter has a more pronounced change of clearance angle than a large diameter. In fact, when of an exceedingly large diameter, the circular tool approaches in cutting action the dovetail type of tool which is usually provided with about 10 degrees clearance. Circular tools usually range from about $1\frac{3}{4}$ to 3 inches diameter, depending upon the size of machine in which they are used.

Getting the Tool Diameters at Different Points

In order to make a circular or a dovetail type of tool so that the contour of its cutting edge is such as to produce correct work, the amount a circular tool is cut below center, as at c in Fig. 8, and the clearance angle of a dovetail tool as at A' in Fig. 7 must be known. Thus, referring to Fig. 8, the forming tool shown cuts two different diameters on the work, the step between being represented by dimension a. To find depth f to which the forming tool must be finished on the center line to give the correct depth of cut a in the work (the cutter being milled below center an amount represented by c), the following formula may be applied:

$$f = g - \sqrt{g^2 + a^2 - (2a\sqrt{g^2 - c^2})}.$$

Suppose the depth of cut in the work represented by a to be 0.152 second; the radius g of the forming cutter 1 inch; the distance c

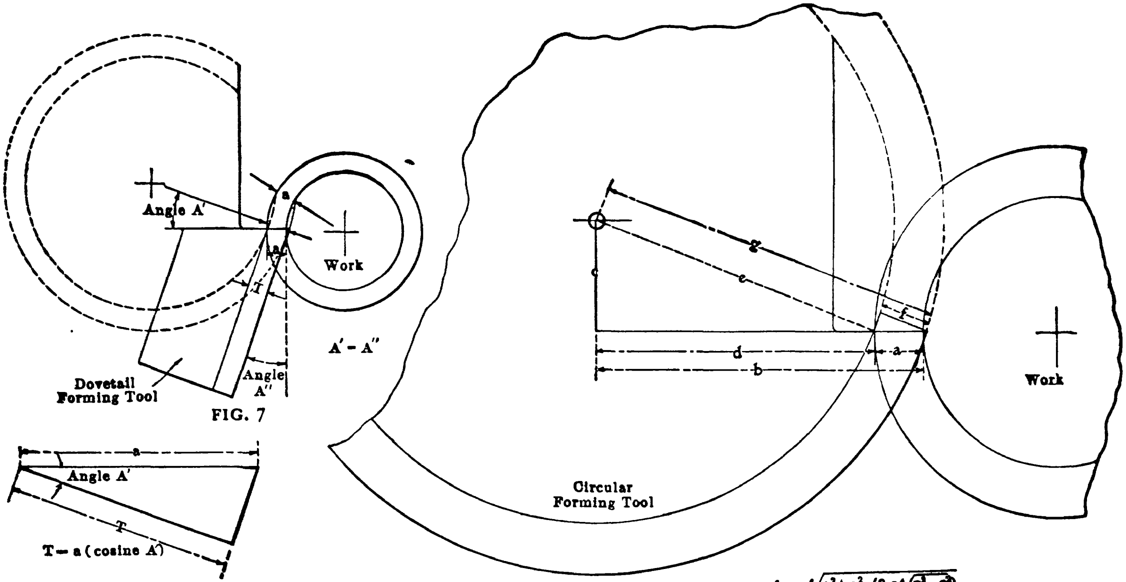


FIG. 7

$T = a\,(\text{cosine } A')$

FIG. 9

$f = g - \sqrt{g^2 + a^2 - (2a\sqrt{g^2 - c^2})}$

FIG. 8

FIGS. 7 to 9.—Forming-Tool Diameters and Depths which the forming tool is milled below center, $\frac{3}{16}$. Applying the formula given to find f and substituting the values just given for the letters in the formula we have

$$\begin{aligned} f &= 1 - \sqrt{1 + 0.0231 - (0.304\sqrt{1 - 0.03516})} \\ &= 1 - \sqrt{1 + 0.0231 - (0.304 \times 0.9823)} \\ &= 1 - \sqrt{0.724485} = 1 - 0.8512 = 0.1488. \end{aligned}$$

Then $f = 0.1488$

Dovetail-Tool Depths

If a similar piece of work is to be formed with a dovetail type of cutter, the distance T, Figs. 7 and 9, to which it is necessary to plane the tool shoulder in order that it may cut depth a correctly in the work, is found by the formula: $T = a\ (\cos A')$. As 10 degrees is the customary clearance on this form of tool, the cosine of this angle, which is 0.98481, may be considered as a constant, making reference to a table of cosines unnecessary as a rule. Assuming the same depth for a as in the previous case, that is, 0.152 inch, and multiplying by 0.98481, we have 0.1496 inch as the depth of T to which the tool must be planed.

Making Forming Tools

As already stated, since the top of a formed tool is flat and is set on the center line of the work, as illustrated in Fig. 6, and since it is held at an angle, it will readily be seen that the outline at the top and that on the line *AA* will vary with the angle. This variation is illustrated in Fig. 6. If a piece of round stock is cut off on the line *AA*, its section will be circular, but if the cut is made on the line *BB*, the section will be elliptical. Thus, change of form caused by the angle at which the tool is held must always be taken into consideration in making formed tools.

As a practical example of the method to be followed in making a dovetail formed tool, let it be assumed that the work it is to do is to produce the part *A* in Fig. 10. Either from a sample of the work or from a drawing, matched templets, as at *B* and *C*, should be made of tool steel about $\frac{1}{32}$ inch thick, and the outlines must be worked out accurately.

The next step is to make the master tool *D*. This tool should be about $\frac{3}{8}$ inch thick, and the outline must be worked out carefully to fit templet *B*. A hole is drilled in the master tool for a screw to secure it in the toolholder, after which it is hardened and then drawn to a medium straw color, assuming that the material is carbon steel.

The fixtures used in planing a dovetail tool are illustrated in Fig. 11. The fixture in which the blank for the formed tool is held is attached to the shaper table, the blank being located by its dovetail and secured by screws bearing against a gib. The master tool *D* is held in its holder at an angle of 10 degrees in transferring its outline to the formed tool. Thus it follows that when the formed tool is held at the same angle in the machine in which it is to be used, it will impart the desired outline to the work.

It is obvious that the master tool has a negative rake when applied to the formed tool. Thus it cannot really cut; the best it can do is to scrape. For this reason, the outline on the formed tool should be first worked out with ordinary tools until it is approximately correct. To expedite this operation, it is a good plan to solder templet *C*, Fig. 10, to a bracket in which it will incline forward at the top at an angle of 10 degrees, as shown in Fig. 12. With the templet thus held at the correct angle, it can be used as a guide in roughing out the formed tool.

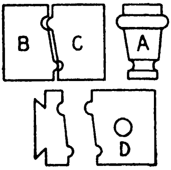


FIG. 10

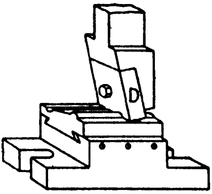


FIG. 11

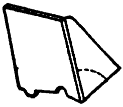


FIG. 12

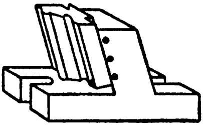


FIG. 13

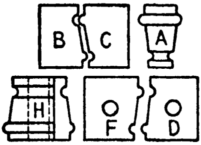


FIG. 14

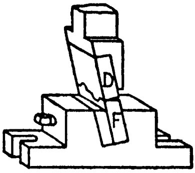


FIG. 15

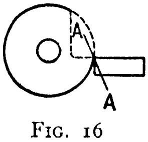


FIG. 16

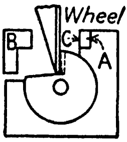


FIG. 17

FIGS. 10–17.—Steps in Making Dovetail and Circular Forming Tools

When the outline is approximately correct, the master tool *D* is set in place to complete the operation, as shown in Fig. 11. Every precaution must be taken to prevent the master from tearing the surface of the formed tool. A shaper, run at its slowest speed, should be used. Very light cuts should be taken and the tool should be well lubricated with genuine lard oil.

After the outline has been finished on the formed tool, the formed tool is held in the fixture illustrated in Fig. 13 and the top is planed off. The fixture consists of a block to hold the tool at the desired angle by means of screws bearing against a gib on one side of the dovetail. After the formed tool has been hardened and drawn, it is held in the same fixture in the surface grinder for grinding the top smooth. This fixture is also used in sharpening the tool as occasion requires.

The method to be followed in making formed tools of the circular type differs slightly from that used in making dovetail tools. In Fig. 5 it will be seen that the cutting edge of the tool is below its center. The line *BB* is in line with the center of the work. Thus, the toolholder must have its hole for the stud above the center of the work the same amount as the distance between the lines *AA* and *BB*. The amount of this clearance will vary with different machines in which the tools are to be used.

The procedure to be followed in making a formed tool of the circular type is indicated in Fig. 14, where *A* is the work to be produced. Matched templets *B* and *C* are made as in the case of the dovetail tool. The master tool *D* is made to fit templet *C*. A second master tool *F* is made from the first one and is used to turn the form on the circular tool *H*. In Fig. 15 it will be seen that in finishing the second master tool the first master tool is held in a holder inclined at about 10 degrees and that the second master tool is held at the same angle in a fixture attached to the shaper table.

In turning the form on the circular tool with the second master tool, the master tool must be set below the center the predetermined distance between the lines *AA* and *BB* in Fig. 5. Thus, when the circular tool has been put in use, when line *BB* is brought into line with the center of the work, the correct contour will, of necessity, be formed on the work.

In using the second master tool to turn the form on the circular tool, due care must be taken to use very light cuts, for a tool of any kind used below the center is likely to cause the work to rise or spring upward.

The object of the 10-degree angle on the second master tool is to give the clearance *AA*, Fig. 16, so it will cut properly. After the circular tool has been turned to shape, it is gashed by cutting away the portion indicated by the dotted lines. It is than hardened and drawn and sharpened ready for use. In sharpening the tool, the fixture in Fig. 17 is useful. The dotted lines indicate the metal to be ground off. The fixture is used on the surface grinder. The block *A* is hardened and the offset gage *B* is used for checking the distance of the cutting surface of the tool from surface *C* of the block; it being understood that the correct relation exists between the surface *C* of block *A* and the stud on which the tool is located.

Circular Tool for Conical Points

When a circular cutter is to be made for forming a conical surface on a piece, as in Fig. 18, a master tool of the exact angle required on the work may be used for finishing the cutter in the same way as the tool in Fig. 9 is applied; that is, the master is to be dropped below center the amount the cutter center is to be above the work center when in operation. The distance is represented by D in Fig. 18. Another method, which avoids the necessity of making a master tool, is to set the compound rest of the lathe to the exact angle required (in this case 30 degrees with the center line) and with a horizontal cutting tool set at distance D below center, turn off one side of the cutter blank and then set the compound rest around the other way and face off the other side. If desired a similar method may be followed for grinding the forming cutter after hardening. The arbor carrying the cutter should be located either above or below the grinding wheel a distance equal to $D\frac{(R+r)}{r}$, where D equals the depth the cutter is milled below center, r the radius of the cutter, and R the radius of the grinding wheel. Assume D to be 0.187 ($\frac{3}{16}$) inch; R, 2.5 inches; and r, 1 inch; the vertical distance between centers of forming tool and grinding wheel centers would equal $0.187\frac{(1+2.5)}{1} = 0.187\ (3.5) = 0.6562$ ($\frac{21}{32}$) inch.

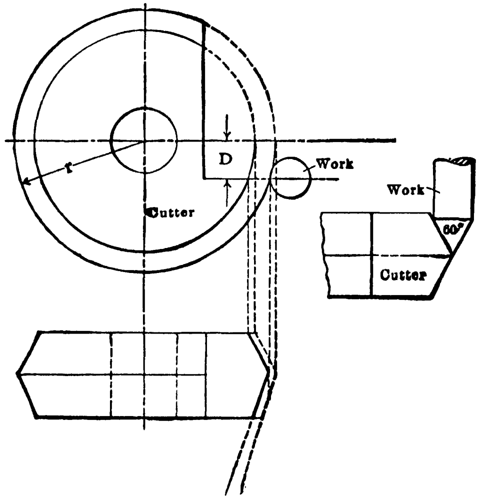


FIG. 18.—Circular Forming Tool for Conical Points

Finding Diameters of Circular Forming Tools

In making circular forming tools it is often desirable to check the finished tool or finish a tool by grinding. It may also be advantageous to know the exact diameter a tool should be turned while making it, in order that calipering may be more convenient and certain. Methods of computing the diameter at different points are given on page 547, but in many cases of this kind the following tables will greatly facilitate matters, particularly when making circular forming tools for Brown and Sharpe automatics.

Suppose, for example, we have a piece to make like Fig. 19 on the No. 2 Brown and Sharpe automatic screw machine. The largest diameter of the circular forming tool would produce the smallest diameter of the piece, which is 0.250 inch. The difference between this 0.250-inch diameter and the step of the 0.750-inch diameter is (0.750 − 0.250 inch) ÷ 2 = 0.250 inch.

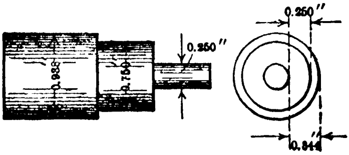


Fig. 19.—The Piece to Be Made

The largest diameter of the circular forming tool for the No. 2 machine is 3 inches, which corresponds to a radius of 1.49998 inches with a base line of 1.479 inches for the triangle completed by perpendicular joining the cutting line of the tool with the parallel line passing through the center of the tool.

The hypotenuse of the triangle is formed by the radius joining the intersection of the base line and the circumference of the tool, as in Fig. 20. Subtracting 0.250 inch from 1.479 inches, we have 1.229 inches, which, in Table 4, corresponds to a radius of 1.25417 inches, and multiplying by 2 gives a diameter of 2.50834 inches, to which to turn the cutter to form correctly the 0.750-inch diameter on the piece, Fig. 19.

Considering the largest diameter of the piece and taking the height of the second step above the first diameter, we have (0.938 − 0.25) ÷ 2 = 0.344 inch, and subtracting from 1.479 = 1.135 for the base line, which, in Table 6, corresponds to a radius of 1.16221. Multiplying by 2 gives a diameter of 2.3244 to turn the cutter to in order to produce the 0.938-inch diameter on the work. Tables 4, 5, and 6 are for cutters of the dimensions given in Table 3.

These tables are figured in steps of 0.001 inch for the capacity of the machines. A difference of a fractional part of a thousandth can be added to the radius if the step is a part of a thousandth over the base-line figures, which are given in even thousandths. For illustration: Say the base-line figure is 1.4765 inches. In Table 6 1.476 inches corresponds to a radius of 1.49702; add 0.0005 inch to 1.49702, and the radius will be as near correct as it is practicable to make a cutter.

Box tools for duralumin should be set a little above the center and have 5 degrees front clearance. Shaving or forming tools work well with 10 degrees shear and 10 degrees front clearance.

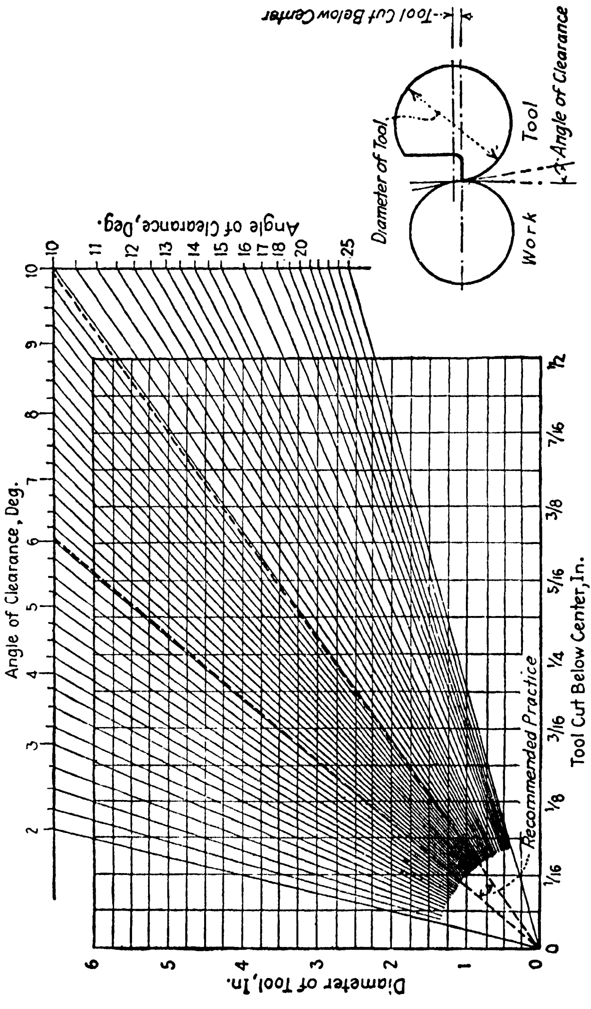


FIG. 20.—Chart for Circular Tools

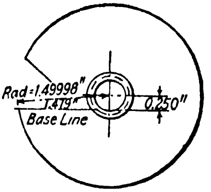


TABLE 3.—DIMENSIONS OF CUTTERS FOR B. & S. AUTOMATIC SCREW MACHINES

(Dimensions in Inches)

Mach. No.	Approx. Diam.	Max. Radius	Max. Base Line	Distance above or below Center
2 & 2G	3	1.49998	1.479	0.250
0 & 0G	2.250	1.12474	1.114	0.15625
00 & 00G	1.750	0.87497	0.866	0.125

TABLE 4.—FINDING DIAMETERS OF CIRCULAR FORMING TOOLS FOR BROWN & SHARPE NO. 00 AUTOMATIC SCREW MACHINE

No. 00 & 00G		No. 00 & 00G		No. 00 & 00G		No. 00 & 00G		No. 00 & 00G	
Base Line	Radius	Base Line	Radius	Base Line	Radius	Base Line	Radius	Base Line	Radius
.866	.87497	.841	.85024	.815	.82453	.789	.79884	.763	.77317
.865	.87398	.840	.84925	.814	.82354	.788	.79785	.762	.77218
.864	.87300	.839	.84826	.813	.82255	.787	.79686	.761	.77120
.863	.87201	.838	.84727	.812	.82156	.786	.79588	.760	.77021
.862	.87102	.837	.84628	.811	.82058	.785	.79489	.759	.76922
.861	.87003	.836	.84529	.810	.81959	.784	.79390	.758	.76823
.860	.86904	.835	.84430	.809	.81860	.783	.79291	.757	.76725
.859	.86805	.834	.84332	.808	.81761	.782	.79193	.756	.76626
.858	.86706	.833	.84233	.807	.81662	.781	.79094	.755	.76528
.857	.86607	.832	.84134	.806	.81564	.780	.78995	.754	.76429
.856	.86508	.831	.84035	.805	.81465	.779	.78896	.753	.76330
.855	.86409	.830	.83936	.804	.81366	.778	.78798	.752	.76232
.854	.86310	.829	.83837	.803	.81267	.777	.78699	.751	.76133
.853	.86211	.828	.83738	.802	.81168	.776	.78600	.750	.76035
.852	.86112	.827	.83639	.801	.81069	.775	.78502	.749	.75936
.851	.86013	.826	.83540	.800	.80971	.774	.78403	.748	.75837
.850	.85914	.825	.83442	.799	.80872	.773	.78304	.747	.75739
.849	.85815	.824	.83343	.798	.80773	.772	.78205	.746	.75640
.848	.85716	.823	.83244	.797	.80674	.771	.78107	.745	.75541
.847	.85617	.822	.83145	.796	.80576	.770	.78008	.744	.75443
.846	.85518	.821	.83046	.795	.80477	.769	.77909	.743	.75344
.845	.85420	.820	.82947	.794	.80378	.768	.77811	.742	.75246
.844	.85321	.819	.82848	.793	.80279	.767	.77712	.741	.75147
.843	.85222	.818	.82750	.792	.80180	.766	.77613	.740	.75048
.842	.85123	.817	.82651	.791	.80082	.765	.77515		
		.816	.82552	.790	.79983	.764	.77416		

NOTE.—In Tables 4, 5 and 6, it should be noted, as explained on page 553, that the base-line dimensions in the columns under that heading and in the diagram, Fig. 21, are actually the distance of the cutting edge of the tool from the center of the cutter, the latter being used in the machine a certain distance either above or below the spindle center corresponding to Table 1. The distance from the cutting edge to center is, therefore, shorter than the true cutter radius by the amount indicated in the tables.

TABLE 5.—FINDING DIAMETERS OF CIRCULAR FORMING TOOLS FOR BROWN & SHARPE NO. 0 AUTOMATIC SCREW MACHINE—*Continued*

No. 0		No. 0		No. 0		No. 0		No. 0	
Base Line	Radius	Base Line	Radius	Base Line	Radius	Base Line	Radius	Base Line	Radius
1.114	1.12474	1.060	1.07143	1.010	1.02159	.960	.97263	.910	.92331
1.113	1.12376	1.059	1.07044	1.009	1.02059	.959	.97165	.909	.92233
1.112	1.12278	1.058	1.06945	1.008	1.01959	.958	.97067	.908	.92135
1.111	1.12180	1.057	1.06845	1.007	1.01860	.957	.96969	.907	.92036
1.110	1.12082	1.056	1.06746	1.006	1.01760	.956	.96871	.906	.91938
1.109	1.11984	1.055	1.06646	1.005	1.01660	.955	.96773	.905	.91840
1.108	1.11886	1.054	1.06547	1.004	1.01560	.954	.96675	.904	.91742
1.107	1.11788	1.053	1.06448	1.003	1.01461	.953	.96578	.903	.91644
1.106	1.11690	1.052	1.06349	1.002	1.01361	.952	.96481	.902	.91546
1.105	1.11592	1.051	1.06250	1.001	1.01261	.951	.96383	.901	.91448
1.104	1.11494	1.050	1.06151	1.000	1.01162	.950	.96285	.900	.91349
1.103	1.11396	1.049	1.06051	.999	1.01065	.949	.96186		
1.102	1.11298	1.048	1.05951	.998	1.00968	.948	.96087		
1.101	1.11200	1.047	1.05851	.997	1.00871	.947	.95988		
1.100	1.11103	1.046	1.05751	.996	1.00774	.946	.95889		
1.099	1.11004	1.045	1.05652	.995	1.00677	.945	.95790		
1.098	1.10905	1.044	1.05552	.994	1.00580	.944	.95691		
1.097	1.10806	1.043	1.05452	.993	1.00483	.943	.95592		
1.096	1.10707	1.042	1.05352	.992	1.00386	.942	.95492		
1.095	1.10608	1.041	1.05252	.991	1.00289	.941	.95393		
1.094	1.10509	1.040	1.05153	.990	1.00192	.940	.95294		
1.093	1.10410	1.039	1.05053	.989	1.00096	.939	.95195		
1.092	1.10311	1.038	1.04953	.988	.99993	.938	95096		
1.091	1.10212	1.037	1.04853	.987	.99897	.937	.94997		
1.090	1.10113	1.036	1.04753	.986	.99800	.936	.94898		
1.089	1.10014	1.035	1.04653	.985	.99704	.935	.94799		
1.088	1.09915	1.034	1.04554	.984	.99608	.934	.94700		
1.087	1.09816	1.033	1.04454	.983	.99512	.933	.94601		
1.086	1.09717	1.032	1.04354	.982	.99416	.932	.94502		
1.085	1.09618	1.031	1.04254	.981	.99320	.931	.94403		
1.084	1.09519	1.030	1.04154	.980	.99224	.930	.94303		
1.083	1.09420	1.029	1.04055	.979	.99128	.929	.94201		
1.082	1.09321	1.028	1.03955	.978	.99032	.928	.94102		
1.081	1.09222	1.027	1.03855	.977	.98936	.927	.94003		
1.080	1.09123	1.026	1.03755	.976	.98840	.926	.93905		
1.079	1.09024	1.025	1.03656	.975	.98743	.925	.93807		
1.078	1.08925	1.024	1.03556	.974	.98645	.924	.93709		
1.077	1.08826	1.023	1.03456	.973	.98547	.923	.93611		
1.076	1.08727	1.022	1.03356	.972	.98449	.922	.93513		
1.075	1.08629	1.021	1.03256	.971	.98351	.921	.93415		
1.074	1.08530	1.020	1.03157	.970	.98253	.920	.93317		
1.073	1.08431	1.019	1.03057	.969	.98155	.919	.93219		
1.072	1.08332	1.018	1.02957	.968	.98057	.918	.93121		
1.071	1.08233	1.017	1.02857	.967	.97958	.917	.93023		
1.070	1.08134	1.016	1.02757	.966	.97859	.916	.92925		
1.069	1.08035	1.015	1.02658	.965	.97760	.915	.92826		
1.068	1.07936	1.014	1.02558	.964	.97661	.914	.92727		
1.067	1.07837	1.013	1.02458	.963	.97561	.913	.92628		
1.066	1.07738	1.012	1.02358	.962	.97462	.912	.92529		
1.065	1.07639	1.011	1.02258	.961	.97362	.911	.92430		
1.064	1.07540								
1.063	1.07441								
1.062	1.07342								
1.061	1.07243								

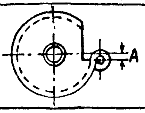
TABLE 6.—FOR FINDING DIAMETERS OF CIRCULAR FORMING TOOLS FOR BROWN & SHARPE NO. 2 AUTOMATIC SCREW MACHINE

No. 2 & 2G		No. 2 & 2G		No. 2 & 2G		No. 2 & 2G		No. 2 & 2G	
Base Line	Radius	Base Line	Radius	Base Line	Radius	Base Line	Radius	Base Line	Radius
1.479	1.49998	1.430	1.45168	1.380	1.40246	1.330	1.35329	1.280	1.30419
1.478	1.49899	1.429	1.45070	1.379	1.40148	1.329	1.35231	1.279	1.30320
1.477	1.49801	1.428	1.44982	1.378	1.40050	1.328	1.35133	1.278	1.30222
1.476	1.49702	1.427	1.44873	1.377	1.39952	1.327	1.35035	1.277	1.30124
1.475	1.49604	1.426	1.44775	1.376	1.39853	1.326	1.34936	1.276	1.30026
1.474	1.49505	1.425	1.44676	1.375	1.39754	1.325	1.34838	1.275	1.29928
1.473	1.49406	1.424	1.44578	1.374	1.39656	1.324	1.34740	1.274	1.29830
1.472	1.49308	1.423	1.44479	1.373	1.39558	1.323	1.34641	1.273	1.29732
1.471	1.49209	1.422	1.44381	1.372	1.39459	1.322	1.34543	1.272	1.29633
1.470	1.49110	1.421	1.44282	1.371	1.39360	1.321	1.34445	1.271	1.29535
1.469	1.49012	1.420	1.44184	1.370	1.39262	1.320	1.34347	1.270	1.29437
1.468	1.48913	1.419	1.44085	1.369	1.39164	1.319	1.34248	1.269	1.29339
1.467	1.48815	1.418	1.43987	1.368	1.39066	1.318	1.34150	1.268	1.29241
1.466	1.48716	1.417	1.43874	1.367	1.38967	1.317	1.34052	1.267	1.29143
1.465	1.48618	1.416	1.43790	1.366	1.38869	1.316	1.33954	1.266	1.29045
1.464	1.48519	1.415	1.43690	1.365	1.38770	1.315	1.33855	1.265	1.28947
1.463	1.48421	1.414	1.43593	1.364	1.38672	1.314	1.33757	1.264	1.28848
1.462	1.48322	1.413	1.43495	1.363	1.38574	1.313	1.33659	1.263	1.28750
1.461	1.48223	1.412	1.43396	1.362	1.38475	1.312	1.33560	1.262	1.28652
1.460	1.48125	1.411	1.43298	1.361	1.38377	1.311	1.33462	1.261	1.28554
1.459	1.48026	1.410	1.43199	1.360	1.38279	1.310	1.33364	1.260	1.28456
1.458	1.47928	1.409	1.43100	1.359	1.38181	1.309	1.33266	1.259	1.28358
1.457	1.47829	1.408	1.43002	1.358	1.38082	1.308	1.33168	1.258	1.28260
1.456	1.47731	1.407	1.42905	1.357	1.37984	1.307	1.33069	1.257	1.28162
1.455	1.47632	1.406	1.42805	1.356	1.37885	1.306	1.32971	1.256	1.28064
1.454	1.47534	1.405	1.42707	1.355	1.37786	1.305	1.32873	1.255	1.27965
1.453	1.47435	1.404	1.42608	1.354	1.37689	1.304	1.32775	1.254	1.27868
1.452	1.47337	1.403	1.42510	1.353	1.37590	1.303	1.32677	1.253	1.27770
1.451	1.47238	1.402	1.42411	1.352	1.37492	1.302	1.32578	1.252	1.27672
1.450	1.47139	1.401	1.42313	1.351	1.37393	1.301	1.32480	1.251	1.27574
1.449	1.47041	1.400	1.42215	1.350	1.37295	1.300	1.32382	1.250	1.27476
1.448	1.46944	1.399	1.42116	1.349	1.37197	1.299	1.32284	1.249	1.27377
1.447	1.46846	1.398	1.42017	1.348	1.37098	1.298	1.32186	1.248	1.27279
1.446	1.46745	1.397	1.41919	1.347	1.37000	1.297	1.32087	1.247	1.27181
1.445	1.46647	1.396	1.41821	1.346	1.36902	1.296	1.31989	1.246	1.27083
1.444	1.46548	1.395	1.41723	1.345	1.36804	1.295	1.31891	1.245	1.26985
1.443	1.46459	1.394	1.41624	1.344	1.36705	1.294	1.31793	1.244	1.26887
1.442	1.46351	1.393	1.41526	1.343	1.36607	1.293	1.31695	1.243	1.26789
1.441	1.46253	1.392	1.41427	1.342	1.36509	1.292	1.31596	1.242	1.26691
1.440	1.46154	1.391	1.41329	1.341	1.36410	1.291	1.31498	1.241	1.26593
1.439	1.46056	1.390	1.41230	1.340	1.36312	1.290	1.31400	1.240	1.26495
1.438	1.45957	1.389	1.41132	1.339	1.36214	1.289	1.31301	1.239	1.26397
1.437	1.45853	1.388	1.41033	1.338	1.36116	1.288	1.31203	1.238	1.26299
1.436	1.45759	1.387	1.40935	1.337	1.36017	1.287	1.31106	1.237	1.26201
1.435	1.45661	1.386	1.40837	1.336	1.35919	1.286	1.31008	1.236	1.26103
1.434	1.45563	1.385	1.40738	1.335	1.35820	1.285	1.30909	1.235	1.26005
1.433	1.45464	1.384	1.40640	1.334	1.35722	1.284	1.30811	1.234	1.25907
1.432	1.45366	1.383	1.40541	1.333	1.35624	1.283	1.30713	1.233	1.25809
1.431	1.45267	1.382	1.40443	1.332	1.35526	1.282	1.30615	1.232	1.25711
		1.381	1.40345	1.331	1.35428	1.281	1.30517	1.231	1.25613

TABLE 6.—FOR FINDING DIAMETERS OF CIRCULAR FORMING TOOLS FOR BROWN & SHARPE NO. 2 AUTOMATIC SCREW MACHINE—*Continued*

No. 2 & 2G		No. 2 & 2G		No. 2 & 2G		No. 2 & 2G		No. 2 & 2G	
Base Line	Radius	Base Line	Radius	Base Line	Radius	Base Line	Radius	Base Line	Radius
1.230	1.25515	1.178	1.20424	1.126	1.15342	1.074	1.10271	1.022	1.05213
1.229	1.25417	1.177	1.20326	1.125	1.15244	1.073	1.10174	1.021	1.05116
1.228	1.25319	1.176	1.20228	1.124	1.15147	1.072	1.10076	1.020	1.05019
1.227	1.25221	1.175	1.20130	1.123	1.15049	1.071	1.09979	1.019	1.04920
1.226	1.25123	1.174	1.20032	1.122	1.14951	1.070	1.09882	1.018	1.04825
1.225	1.25025	1.173	1.19934	1.121	1.14854	1.069	1.09784	1.017	1.04728
1.224	1.24927	1.172	1.19837	1.120	1.14756	1.068	1.09687	1.016	1.04631
1.223	1.24829	1.171	1.19739	1.119	1.14659	1.067	1.09590	1.015	1.04533
1.222	1.24731	1.170	1.19641	1.118	1.14561	1.066	1.09492	1.014	1.04436
1.221	1.24633	1.169	1.19543	1.117	1.14463	1.065	1.09395	1.013	1.04339
1.220	1.24535	1.168	1.19446	1.116	1.14366	1.064	1.09298	1.012	1.04242
1.219	1.24437	1.167	1.19348	1.115	1.14268	1.063	1.09200	1.011	1.04145
1.218	1.24339	1.166	1.19250	1.114	1.14171	1.062	1.09103	1.010	1.04048
1.217	1.24241	1.165	1.19152	1.113	1.14073	1.061	1.09006	1.009	1.03951
1.216	1.24143	1.164	1.19054	1.112	1.13976	1.060	1.08908	1.008	1.03854
1.215	1.24045	1.163	1.18957	1.111	1.13878	1.059	1.08811	1.007	1.03757
1.214	1.23947	1.162	1.18859	1.110	1.13780	1.058	1.08714	1.006	1.03660
1.213	1.23849	1.161	1.18761	1.109	1.13683	1.057	1.08616	1.005	1.03563
1.212	1.23752	1.160	1.18663	1.108	1.13586	1.056	1.08519	1.004	1.03466
1.211	1.23654	1.159	1.18566	1.107	1.13488	1.055	1.08422	1.003	1.03369
1.210	1.23556	1.158	1.18468	1.106	1.13390	1.054	1.08324	1.002	1.03273
1.209	1.23458	1.157	1.18370	1.105	1.13293	1.053	1.08227	1.001	1.03175
1.208	1.23360	1.156	1.18272	1.104	1.13195	1.052	1.08130	1.000	1.03078
1.207	1.23262	1.155	1.18175	1.103	1.13098	1.051	1.08032	.999	1.02981
1.206	1.23164	1.154	1.18077	1.102	1.13000	1.050	1.07935	.998	1.02884
1.205	1.23066	1.153	1.17979	1.101	1.12903	1.049	1.07838	.997	1.02787
1.204	1.22968	1.152	1.17881	1.100	1.12805	1.048	1.07741	.996	1.02690
1.203	1.22870	1.151	1.17784	1.099	1.12708	1.047	1.07643	.995	1.02593
1.202	1.22772	1.150	1.17686	1.098	1.12610	1.046	1.07546	.994	1.02496
1.201	1.22675	1.149	1.17588	1.097	1.12513	1.045	1.07449	.993	1.02399
1.200	1.22577	1.148	1.17491	1.096	1.12415	1.044	1.07352	.992	1.02302
1.199	1.22479	1.147	1.17393	1.095	1.12318	1.043	1.07254	.991	1.02205
1.198	1.22381	1.146	1.17295	1.094	1.12220	1.042	1.07157	.990	1.02108
1.197	1.22283	1.145	1.17197	1.093	1.12123	1.041	1.07060	.989	1.02011
1.196	1.22185	1.144	1.17100	1.092	1.12025	1.040	1.06963	.988	1.01914
1.195	1.22087	1.143	1.17002	1.091	1.11928	1.039	1.06865	.987	1.01817
1.194	1.21989	1.142	1.16904	1.090	1.11830	1.038	1.06768	.986	1.01720
1.193	1.21891	1.141	1.16807	1.089	1.11733	1.037	1.06671	.985	1.01623
1.192	1.21793	1.140	1.16709	1.088	1.11635	1.036	1.06574	.984	1.01526
1.191	1.21696	1.139	1.16612	1.087	1.11538	1.035	1.06477	.983	1.01429
1.190	1.21598	1.138	1.16514	1.086	1.11440	1.034	1.06379	.982	1.01332
1.189	1.21500	1.137	1.16416	1.085	1.11343	1.033	1.06282	.981	1.01235
1.188	1.21402	1.136	1.16318	1.084	1.11246	1.032	1.06185	.980	1.01139
1.187	1.21304	1.135	1.16221	1.083	1.11148	1.031	1.06088	.979	1.01042
1.186	1.21206	1.134	1.16123	1.082	1.11051	1.030	1.05991	.978	1.00945
1.185	1.21108	1.133	1.16025	1.081	1.10953	1.029	1.05893	.977	1.00848
1.184	1.21011	1.132	1.15928	1.080	1.10856	1.028	1.05796	.976	1.00751
1.183	1.20913	1.131	1.15830	1.079	1.10758	1.027	1.05699	.975	1.00654
1.182	1.20815	1.130	1.15732	1.078	1.10661	1.026	1.05602	.974	1.00557
1.181	1.20717	1.129	1.15635	1.077	1.10563	1.025	1.05505	.973	1.00460
1.180	1.20619	1.128	1.15537	1.076	1.10466	1.024	1.05408	.972	1.00363
1.179	1.20521	1.127	1.15440	1.075	1.10369	1.023	1.05310	.971	1.00267
								.970	1.00170

TABLE 7.—CALCULATING DIAMETERS ON CIRCULAR TOOLS[1]

	Machine Where Used		
	00 and 00G	0 and 0G	2 and 2G
Diameter of Tool	1.750	2.250	3.000
Dimension A	1/8	5/32	1/4

Difference in Diameter of Piece	Difference in Diameter of Tool			Amount of Radial Difference		
	Machine					
•	00 and 00G	0 and 0G	2 and 2G	00 and 00G	0 and 0G	2 and 2G
0.0625	0.062	0.062	0.0615	0.0005	0.0005	0.001
0.125	0.124	0.124	0.123	0.001	0.001	0.002
0.1875	0.1855	0.1855	0.1855	0.002	0.002	0.0025
0.250	0.247	0.2475	0.246	0.003	0.0025	0.004
0.3125	0.3085	0.309	0.3075	0.004	0.0035	0.005
0.375	0.370	0.371	0.369	0.005	0.004	0.006
0.4375		0.432	0.4305		0.0055	0.007
0.500		0.494	0.492		0.006	0.008
0.5625		0.555	0.553		0.0075	0.0095
0.625		0.617	0.614		0.008	0.011
0.6875			0.675			0.0125
0.750			0.736			0.014
0.8125			0.797			0.0155
0.875			0.858			0.017
0.9375			0.9185			0.019
1.000			0.979			0.021
1.0625			1.040			0.0225
1.125			1.100			0.025

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[1] Brown & Sharpe Mfg. Co.

Corrected Diameters for Circular Form Tools

Another method of calculating diameters of circular form tools for screw machines is given by B. S. Sample, of Tool Design Department of Delco-Remy Division, General Motors Corporation. This method, which is stated to be faster than the usual methods, has for its basis the use of tables of cotangents and cosecants. The accompanying Table 7*a* shows the procedure used In practice the information necessary is listed on tracing paper, and white background prints are used for the actual calculation of each tool.

The method of calculation will be described for an actual case. Assume a tool outside diameter of 3.375 inches, an offset of 1/4 inch,

TABLE 7a.—CALCULATIONS FOR CIRCULAR FORM TOOLS WITHOUT RAKE

Off-Set "C"	Tool O.D.	Cotangent A	Off-Set "C"	Tool O.D.	Cotangent A
1/32	1.250	19.97498	5/32	2.500	7.93725
			5/32	2.688	8.54327
1/16	1.688	13.46692	5/32	3.500	11.15527
1/16	2.312	18.46895	5/32	3.750	11.95826
1/16	2.375	18.97367			
1/16	2.750	21.97726	3/16	2.000	5.23875
			3/16	2.250	5.91608
3/32	1.125	5.91608	3/16	2.500	6.59124
3/32	1.250	6.59124	3/16	2.625	6.92820
3/32	1.375	7.26483	3/16	2.750	7.26483
3/32	1.500	7.93725	3/16	3.000	7.93725
3/32	1.750	9.27961			
			1/4	2.840	5.59128
1/8	1.500	5.91608	1/4	3.000	5.91608
1/8	1.750	6.92820	1/4	3.375	6.67552
1/8	1.875	7.43303	1/4	3.875	7.68521
1/8	2.000	7.93725	1/4	4.375	8.69267
1/8	2.312	9.19378	1/4	5.000	9.94988
1/8	2.375	9.44722	1/4	5.250	10.45227
1/8	2.500	9.94988			
1/8	2.750	10.95445	5/16	4.000	6.32139
1/8	3.250	12.96148			
5/32	1.938	6.12044	1/8	3.000	11.95826
5/32	2.250	7.13022	1/16	3.000	23.97916
5/32	2.312	7.33051			

PROOF FORMULAS

$$\cot B = \cot A - \frac{D}{C}$$

$$\text{Corrected Diam.} = \operatorname{Cosec} B \times (2 \times C)$$

FOR TOOLS NOT LISTED

$$\operatorname{cosec} A = \frac{\text{tool O.D}}{2 \times C}$$

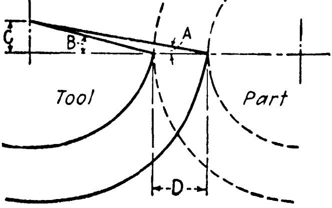
Obtain cot A from
Trig. Tables

CONSTANTS FOR TOOL

$C = \frac{1}{4}$

$\cot A = 6.6755$

$(2 \times C) = \frac{1}{2}$



and a minimum work diameter of 0.426 in. What is the tool diameter necessary to give a diameter of 0.817 inch on the work?

The step *D* is found by subtraction and halving to be 0.1955. This is divided by *C*, or $\frac{1}{4}$, obtaining 0.7820, which is subtracted from the constant 6.6755 (from the chart), giving 5.8935 for the value of cotangent *B*. This is looked up in a table of cotangents, and the corresponding cosecant is found to be 5.9778, which is multiplied by $\frac{1}{2}$, or twice the value of *C*, giving 2.9889 as the corrected tool diameter. The "square and square-root" method gives a value of 2.98890 for this same figure.

The steps for the cotangent-cosecant method are thus seen to be:

1. Division by a simple fraction
2. Subtraction
3. Consulting trigonometric tables
4. Multiplication by a simple fraction

Noteworthy Points.—1. Where the tool offset is a simple fraction, the calculation is easy. For example, to divide 0.1955 by $\frac{1}{4}$, multiply by 4 and obtain 0.7820. Also, to multiply 5.9778 by $\frac{1}{2}$, divide by 2, obtaining 2.9889.

2. All constants in the table of cotangent *A* are based on the fractional value of the offset, to facilitate longhand calculation. If a calculating machine is used, the value of *C* should be carried to four decimal places in order to obtain four-place accuracy in the answer. Although the values of cotangent *A* are given to five decimal places, only four places need be used in the calculations.

3. In the region used on the chart, the tabular difference between cotangents and cosecants is practically the same, so exact interpolation of the tables is not necessary.

4. The answer obtained by this method is accurate within ±1 in the fourth decimal place, which is sufficient for most form tools.

Example.—For a tool $\frac{1}{4} \times 3.375$, calculations follow:

Part Diam.	Step *D*	$\frac{D}{C}$	Cotangent $A - \frac{D}{C}$ Cotangent *B*	From Trigonometric Tables Cosecant *B*	Corr. Diam.
0.426 minimum					
0.817	0.1955	0.7820	5.8935	5.9778	2.9889
0.982	0.253	1.0120	5.6635	5.7512	2.8756
1.000	0.287	1.1480	5.5275	5.6171	2.8085
1.250	0.412	1.6480	5.0275	5.1260	2.5630

Threading Speeds for Taps and Dies

DROP FORGINGS

Diam.	Surface Feet	R.p.m.
$\frac{1}{8}$	25	765
$\frac{3}{16}$	25	509
$\frac{1}{4}$	25	382
$\frac{5}{16}$	23	305
$\frac{3}{8}$	23	235
$\frac{7}{16}$	23	201
$\frac{1}{2}$	23	176
$\frac{9}{16}$	23	156
$\frac{5}{8}$	23	141
$\frac{11}{16}$	23	128
$\frac{3}{4}$	23	117
$\frac{13}{16}$	23	108
$\frac{7}{8}$	23	100
$\frac{15}{16}$	23	94
1	20	77
$1\frac{1}{4}$	20	61
$1\frac{1}{2}$	20	51
2	18	35

Brown & Sharpe Automatic Acorn Dies

SCREW STOCK

$\frac{1}{8}$	28	855
$\frac{1}{4}$	28	428
$\frac{5}{16}$	28	342
$\frac{3}{8}$	28	285
$\frac{7}{16}$	28	244
$\frac{1}{2}$	28	214
$\frac{9}{16}$	28	190
$\frac{5}{8}$	28	171
$\frac{11}{16}$	28	156
$\frac{3}{4}$	28	143
$\frac{13}{16}$	28	132
$\frac{7}{8}$	28	122
$\frac{15}{16}$	28	114
1	28	107

APPROXIMATE CUTTING SPEEDS AND FEEDS FOR STANDARD TOOLS

Please bear in mind these figures are only approximate, to be used as a basis from which proper figures for the job in hand may be calculated. They are averages, and if the work has any features out of the ordinary take these into consideration and alter the figures accordingly.

Feed—is feed per revolution. Speed—is maximum surface speed of stock in feet per minute.

The same feed is used for both carbon and high-speed steel cutting tools, the cutting speed only being different.

Tool	Cut		Brass Free Cutting		Material					
					Mild or Soft Steel 0.10–0.20 % Carbon			Tool Steel 0.80–1.00 % Carbon		
	Width or Depth	Diam. of Hole	Feed	Speed in Surface Feet	Feed	Speed in Surface Feet		Feed	Speed in Surface Feet	
						Carbon Tools	H.S.S. Tools		Carbon Tools	H.S.S. Tools
Boring tools	0.005				0.004	50	75	0.003	30	45
Box tools:										
Roughing	1/32		0 009		0 006	70	105	0.005	40	60
	1/16		0.008		0.005	70	105	0.004	40	60
	1/8		0.005		0.004	70	105	0.003	40	60
	3/16		0.004		0.003	70	105	0 002	40	60
	1/4		0.0035		0.002	70	105	0 0015	40	60
Finishing	0.005		0.010		0.010	70	120	0 006	40	60
Center drills		Under 1/8	0.002		0.0015	50	75	0 001	30	45
		Over 1/8	0.005		0.0025	50	75	0.002	30	45
Cut-off tools:										
Angular			0 0012		0 0006	80	120	0.0004	50	75
Circular	3/64–1/8		0.002		0.0015	80	120	0 001	50	75
Straight	1/16–1/8		0.002		0.0015	80	120	0.001	50	75
Diameter stock under 1/8 inch			0.001		0.0008	80	120	0.0005	50	75
Dies						30			14	

TABLE 8.—SPEEDS AND FEEDS FOR STANDARD TOOLS

The table below is based on the use of high-speed steel tools. The figures are approximate and subject to change with variations in operating conditions and in the nature of the work involved.

Tool Name	Size of Hole, in Inches	Width or Depth of Cut, in Inches	Union Special Carburizing		S.A.E. 1,045		S.A.E. 2,315 S.A.E. 3,115 S.A.E. 4,615		S.A.E. 2,330 Annealed		S.A.E. 3,135 Annealed		S.A.E. 4,130 Annealed	
			Surface, in Feet	Feed, in Inches	Surface, in Feet	Feed, in Inches	Surface, in Feet	Feed, in Inches	Surface, in Feet	Feed, in Inches	Surface, in Feet	Feed, in Inches	Surface, in Feet	Feed, in Inches
		Width												
Form, circular, or dovetail		0.500	130	0.0019	95	0.0014	110	0.0016	115	0.0017	115	0.0017	120	0.0018
		1.000	125	0.0016	91	0.0012	106	0.0013	112	0.0014	112	0.0014	115	0.0014
		1.500	125	0.0014	91	0.001	106	0.0012	112	0.0013	112	0.0013	115	0.0013
		2.000	121	0.0012	88	0.0009	102	0.001	108	0.0011	108	0.0011	112	0.0011
		2.500	117	0.0009	85	0.0007	99	0.0008	105	0.0008	105	0.0008	108	0.0009
Twist drills	0.250		82	0.0038	60	0.0028	69	0.0033	73	0.0034	73	0.0034	76	0.0035
	0.500		82	0.0043	60	0.0031	69	0.0036	73	0.0038	73	0.0038	76	0.004
	0.750		90	0.0052	65	0.0037	76	0.0044	80	0.0045	80	0.0045	83	0.0047
	1.000		90	0.006	65	0.0044	76	0.0051	80	0.0053	80	0.0053	83	0.0055
	1.250		94	0.0068	68	0.005	79	0.0058	84	0.0062	84	0.0062	86	0.0064
		Depth												
Box tool blades		0.125	130	0.0055	95	0.004	110	0.0046	115	0.0049	115	0.005	120	0.005
		0.250	125	0.0051	91	0.0037	106	0.0043	112	0.0045	112	0.0046	115	0.0047
		0.375	121	0.0043	88	0.0031	102	0.0036	108	0.0038	108	0.0039	112	0.004
		0.500	117	0.0035	85	0.0026	99	0.003	105	0.0031	105	0.0032	108	0.0032
Hollow mills		0.062	117	0.0078	85	0.0057	99	0.0066	105	0.007	105	0.007	108	0.0072
		0.125	109	0.0062	80	0.0046	92	0.0053	98	0.0056	98	0.0056	101	0.0058
		0.187	105	0.0055	77	0.004	89	0.0046	95	0.0049	95	0.0049	97	0.005
		0.250	102	0.0051	74	0.0037	86	0.0043	91	0.0045	91	0.0045	94	0.0047

TABLE 8.—SPEEDS AND FEEDS FOR STANDARD TOOLS—*Continued*

Tool Name	Size of Hole, in Inches	Width or Depth of Cut, in Inches	Union Special Carburizing		S.A.E. 1,045		S.A.E. 2,315 S.A.E. 3,115 S.A.E. 4,615		S.A.E. 2,330 Annealed		S.A.E. 3,135 Annealed		S.A.E. 4,130 Annealed	
			Surface, in Feet	Feed, in Inches	Surface, in Feet	Feed, in Inches	Surface, in Feet	Feed, in Inches	Surface, in Feet	Feed, in Inches	Surface, in Feet	Feed, in Inches	Surface, in Feet	Feed, in Inches
Knurl tools—on			130	0.012	95	0.0085	110	0.0099	115	0.011	115	0.011	120	0.011
In turret—off			130	0.024	95	0.017	110	0.0198	115	0.022	115	0.022	120	0.022
Knurl-cross slide			130	0.012	95	0.0085	110	0.0099	115	0.011	115	0.011	120	0.011
Chamfer and facing			156	0.0047–0.0066	114	0.0035–0.0048	132	0.0038–0.0053	140	0.004–0.006	140	0.004–0.006	144	0.004–0.006
Reamers	Under ½,		113	0.0055	83	0.004	96	0.0046	102	0.0049	102	0.0049	104	0.005
	Over ½		113	0.0078	83	0.0057	96	0.0006	102	0.007	102	0.007	104	0.0072
Cutoff		Width 0.062	130	0.0016	95	0.0011	110	0.0013	115	0.0014	115	0.0014	120	0.0015
		0.125	136	0.0019	100	0.0014	116	0.0016	122	0.0017	122	0.0017	126	0.002
		0.187	140	0.0019	103	0.0014	119	0.0016	126	0.0017	126	0.0017	130	0.002
		0.250	148	0.0023	108	0.0017	126	0.002	133	0.0022	133	0.0022	137	0.0024

Union Drawn Steel Company.

TABLE 8.—SPEEDS AND FEEDS FOR STANDARD TOOLS—*Continued*

The table below is based on the use of high-speed tools. The figures are approximate and subject to change with variations in operating conditions and in the nature of the work involved.

Tool Name	Size of Hole, in Inches	Width or Depth of Cut, in Inches	Union Free-cut Bessemer		Union Supercut		S.A.E. 1,020		S.A.E. 1,035		Union Hymo (0.15 to 0.25 Carbon) X1,314 and X1,315		Union Hymo (0.30 to 0.40 Carbon) and X1,335	
			Surface, in Feet	Feed, in Inches	Surface, in Feet	Feed, in Inches	Surface, in Feet	Feed, in Inches	Surface, in Feet	Feed, in Inches	Surface, in Feet	Feed, in Inches	Surface, in Feet	Feed, in Inches
		Width												
Form, circular, or dovetail		0.500	165	0.0025	225	0.003	120	0.0018	115	0.0017	140	0.0021	120	0.0018
		1.000	160	0.002	210	0.0025	115	0.0014	112	0.0014	136	0.0017	115	0.0014
		1.500	160	0.0018	210	0.0025	115	0.0013	112	0.0013	136	0.0015	115	0.0013
		2.000	155	0.0015	205	0.0018	112	0.0011	108	0.0011	132	0.0013	112	0.0011
		2.500	150	0.0012	200	0.0015	108	0.0009	105	0.0008	127	0.001	108	0.0009
Twist drills	0.250		105	0.0045	125	0.0054	76	0.0035	73	0.0034	89	0.004	76	0.0035
	0.500		105	0.005	125	0.006	76	0.004	73	0.0038	89	0.0045	76	0.004
	0.750		115	0.006	140	0.007	83	0.0047	80	0.0045	98	0.0055	83	0.0047
	1.000		115	0.007	140	0.008	83	0.0055	80	0.0053	98	0.0064	83	0.0055
	1.250		120	0.008	145	0.009	86	0.0064	84	0.0062	102	0.007	86	0.0064
		Depth												
Box tool blades		0.125	165	0.007	225	0.0085	120	0.005	115	0.0049	140	0.0059	120	0.005
		0.250	160	0.0065	210	0.008	115	0.0047	112	0.0045	136	0.0055	115	0.0047
		0.375	155	0.0055	205	0.0065	112	0.004	108	0.0038	132	0.0047	112	0.004
		0.500	150	0.0045	200	0.0055	108	0.0032	105	0.0031	127	0.004	108	0.0032

TABLE 8.—SPEEDS AND FEEDS FOR STANDARD TOOLS—*Continued*

Tool Name	Size of Hole, in Inches	Width or Depth of Cut, in Inches	Union Free-cut Bessemer		Union Supercut		S.A.E. 1,020		S.A.E. 1,035		Union Hymo (0.15 to 0.25 Carbon X1,314 and X1,315		Union Hymo (0.30 to 0.40 Carbon) and X1,335	
			Surface, in Feet	Feed, in Inches	Surface, in Feet	Feed, in Inches	Surface, in Feet	Feed, in Inches	Surface, in Feet	Feed, in Inches	Surface, in Feet	Feed, in Inches	Surface, in Feet	Feed, in Inches
Hollow mills		0.062	150	0.010	200	0.012	108	0.0072	105	0.007	127	0.0085	108	0.0072
		0.125	140	0.008	186	0.0096	101	0.0058	98	0.0056	119	0.0068	101	0.0058
		0.187	135	0.007	179	0.0084	97	0.005	95	0.0049	115	0.006	97	0.005
		0.250	130	0.0065	172	0.0073	94	0.0047	91	0.0045	110	0.0055	94	0.0047
Knurl tools—on			165	0.015	225	0.020	120	0.011	115	0.011	140	0.012	120	0.011
In turret—off			165	0.030	225	0.040	120	0.022	115	0.022	140	0.024	120	0.022
Knurl—cross slide			165	0.015	225	0.020	120	0.011	115	0.011	140	0.012	120	0.011
Chamfer and facing			200	0.005–0.007	280	0.008–0.010	144	0.004–0.006	140	0.004–0.006	170	0.005–0.0072	144	0.004–0.006
Reamers	Under ½,		145	0.007	180	0.0085	104	0.005	102	0.0049	123	0.006	104	0.005
	½, or over		145	0.010	180	0.012	104	0.0072	102	0.007	123	0.0085	104	0.0072
		Width												
Cutoff		0.062	165	0.002	225	0.003	120	0.0015	115	0.0014	140	0.0017	120	0.0015
		0.125	175	0.0025	230	0.0035	126	0.002	122	0.0017	149	0.0021	126	0.002
		0.187	180	0.0025	235	0.0035	130	0.002	126	0.0017	153	0.0021	130	0.002
		0.250	190	0.003	250	0.004	137	0.0024	133	0.0022	161	0.0025	137	0.0024

Union Drawn Steel Company.

SPEEDS AND FEEDS FOR SCREW-MACHINE WORK

The accompanying tables are from the practice advocated by the Brown & Sharpe Mfg. Co. They recommend the following speeds for the drive shafts of their automatic screw machines, for all spindle speeds.

No. 00	No. 0	No. 2
120 r.p.m.	180 r.p.m.	120 r.p.m.

The tables are very complete and cover a large variety of work in very compact form.

SPEEDS AND FEEDS FOR STANDARD TOOLS

The tables on pages 562 to 565 give the practice of the Union Drawn Steel Company. They cover speeds and feeds for many grades of steel, using high-speed cutting tools. Steels with special names may be given as follows; special carburizing permits about 15 per cent higher production than S.A.E. 1,020 and responds readily to carburizing. Union "Free Cut" (S.A.E. 1,112) is a Bessemer screw steel, the company's standard for machinability. "Supercut" is high-sulphur screw stock, permitting 35 per cent higher speeds than ordinary screw stock. "Union Hymo" (0.15 to 0.25 per cent carbon) combined machinability of Bessemer screw stock with the greater toughness of open-hearth steels. "High Carbon Hymo" (0.30 to 0.40 per cent carbon) combines strength of S.A.E. 1,035 and 1,040 with machining qualities that permit an average increase of 15 per cent in cutting speeds.

SPEED OF BOLT CUTTERS

These tables are based on a circumferential cutting speed of 25 feet per minute for cast iron and 35 feet per minute for soft steel and iron up to and including 1 inch, and 30 feet per minute for 1½-inch and 2-inch sizes. The speeds are for high-speed steel chasers. Some users run the machines at a higher rate.

The Bignall & Keeler Mfg. Co. suggests a cutting speed of 20 feet per minute for pipe-threading machines with carbon dies and 25 feet for high-speed dies. They find several petroleum-base cutting compounds a good substitute for lard oil on the dies. These speeds are merely guides and can be exceeded in many cases. A safe rule is to run as fast as possible without undue heating of taps or dies.

THREADING SPEEDS IN FEET PER MINUTE FOR PIPE (LANDIS)

Diameter	Materials					
	Merchant Pipe		Cast Iron		Copper Yellow Brass	
	R.P.M.	Surface Speed	R.P.M.	Surface Speed	R.P.M.	Surface Speed
⅛	377	40	471	50	566	60
¼	248	35	354		424	
⅜	198		283		338	
½	150	33	204	45	250	55
¾	120		164		200	
1	87	30	116	40	145	50
1¼	69		92		115	
1½	60		80		101	
2	48		64		81	
2½	33	25	47	35	60	45
3	27		38		49	
3½	24		33		43	
4	21		30		38	
4½	19		27		30	40
5	17.2		24		27	
6	14.4		20		23	
7	12.5		18		20	
8	11.0		11	25	15.4	35
9	7.9	20	9.9		13.9	
10	7.1		8.9		12.4	
11	6.5		8.1		11.4	
12	6.0		7.5		9.0	30
14	5.5		6.8		8.2	
15	5.1		6.4		7.6	
16	4.3	18	6.0		6.0	25
17	4.0		5.6		5.6	
18	3.8		5.3		5.3	
20	3.4		4.8		4.8	

Speeds for cast-iron pipe based on standard pipe thread dimensions.

THREADING SPEEDS IN FEET PER MINUTE (F.P.M.) (LANDIS)
National Coarse Threads

Diameter	Materials											
	Tool Steel (Carbon)		Vanadium Steel, Nickel Steel, Forged Steel, Open Hearth, Monel Metal		Machine Steel, Drawn Steel, Tobin Bronze, Bessemer, Screw Stock		Malleable Iron, Cast Iron		Cast Brass, Bar Brass, Phosphor Bronze, Copper		Fiber, Bakelite, Aluminum, Lead	
	R.P.M.	Surface Speed	R.P.M.	Surface Speed	R.P.M.	Surface Speed	R.P.M.	Surface Speed	R.P.M.	Surface Speed	R.P.M.	Surface Speed
1/4	316	20	535	35	764	50	917	60	1,070	70	1,222	80
5/16	245		428		611		733		856		978	
3/8	183	18	316	30	458	45	560	55	662	65	764	75
7/16	157		262		393		481		568		656	
1/2	137		191	25	316	40	382	50	459	60	535	70
9/16	102	15	170		272		340		407		475	
5/8	92		153		245		306		367		428	
3/4	76		102		178		229		279		330	

⅞	65		87	20	153	35	196	45	241	55	285
1	46	12	76		134		172		210		258
1⅛	41		68		119		153		187		221
1¼	37		55	18	92	30	123	40	153	50	183
1½	31		46		76		102		127		153
1¾	22	10	39		66		87		109		131
2	19		29	15	48	25	67	35	86	45	105
2¼	17		25		42		59		76		94
2½	15		23		38		53		69		84
2¾	11	8	21		35		49		62		77
3	10		13	10	26	20	38	30	51	40	64

Cutting speeds listed are for annealed stock only. When heat treated material is threaded decrease cutting speed 20 to 30 per cent.

THREADING SPEEDS IN FEET PER MINUTE (F.P.M.) (LANDIS)
National Fine Threads

Diameter	Tool Steel (Carbon)		Vanadium Steel, Nickel Steel, Forged Steel, Open Hearth, Monel Metal		Machine Steel, Drawn Steel, Tobin Bronze, Bessemer, Screw Stock		Malleable Iron, Cast Iron		Cast Brass, Bar Brass, Phosphor Bronze, Copper		Fiber, Bakelite, Aluminum, Lead	
	Materials											
	R.P.M.	Surface Speed	R.P.M.	Surface Speed	R.P.M.	Surface Speed	R.P.M.	Surface Speed	R.P.M.	Surface Speed	R.P.M.	Surface Speed
$\frac{1}{4}$	382	25	611	40	764	50	917	60	1,222	80	1,222	80
$\frac{5}{16}$	306		489		611		733		978		978	
$\frac{3}{8}$	255		357	35	458	45	611		815		815	
$\frac{7}{16}$	175	20	306		393		524		656	75	699	
$\frac{1}{2}$	153		268		344		459		573		611	
$\frac{9}{16}$	136		238		306		373	55	475	70	543	
$\frac{5}{8}$	122		214		276		337		428		489	
$\frac{3}{4}$	92		153		203	40	254		357		381	

$\frac{7}{8}$	79	18	131	30	153	35	219	50	285	65	329	**75**
1	69		115		134		191		258		287	
1$\frac{1}{8}$	61		85	25	119		153	45	204	60	255	
1$\frac{1}{4}$	46	15	76		107		137		183		214	**70**
1$\frac{1}{2}$	38		64		89		115		153		178	
1$\frac{3}{4}$	33		44	20	66	30	87	40	120	55	153	
2	29		38		57		76		105		124	65
2$\frac{1}{4}$	20	12	25	15	42	25	59	35	85	50	111	
2$\frac{1}{2}$	18		23		38		54		76		99	
2$\frac{3}{4}$	17		21		35		49		69		83	60
3	15		19		32		45		64		76	

Cutting speeds listed are for annealed stock only. When heat treated material is threaded decrease cutting speed 20 to 30 per cent.

Surface Speed and Revolutions per Minute

Surface speed	5	8	10	15	20	25	30	40	50	80	100	150	200
Diam. of Work, Inches	R.p.m.												
⅛	152	245	305	458	611	764	917	1222	1528	2445	3056	4584	6112
¼	76.5	122	153	229	306	382	458	611	764	1222	1528	2292	3056
⅜	51.0	81.4	102	153	204	255	306	407	509	815	1019	1528	2038
½	38.2	61.2	76.5	115	153	191	229	306	382	611	764	1146	1528
⅝	30.5	48.8	61.0	91.7	122	153	183	244	306	489	611	917	1222
¾	25.5	40.8	51.0	76.4	102	127	153	204	255	407	509	764	1018
⅞	21.8	35.0	43.6	65.5	87.3	109	131	175	218	349	437	655	874
1	19.1	30.6	38.2	57.3	76.4	95.5	115	153	191	306	382	573	764
1⅛	16.9	27.2	33.9	50.9	67.9	84.9	102	136	170	272	340	509	680
1¼	15.2	24.4	30.5	45.8	61.1	76.4	91.7	122	153	244	306	458	612
1⅜	13.9	22.2	27.8	41.7	55.6	69.5	83.3	111	139	222	278	417	556
1½	12.7	20.4	25.4	38.2	50.9	63.7	76.4	102	127	204	255	382	510
1⅝	11.7	18.8	23.5	35.3	47.0	58.8	70.5	94.0	118	188	235	353	470
1¾	10.9	17.4	21.8	32.7	43.7	54.6	65.5	87.3	109	175	218	327	436
1⅞	10.1	16.3	20.3	30.6	40.7	50.9	61.1	81.5	102	163	204	306	408
2	9.5	15.3	19.1	28.7	38.2	47.7	57.3	76.4	95.5	153	191	287	382
2⅛	9.0	14.4	18.0	27.0	36.0	45.0	54.0	72.0	90.0	144	180	270	360
2¼	8.5	13.6	17.0	25.5	34.0	42.4	50.9	67.9	84.9	136	170	255	340
2⅜	8.0	12.9	16.1	24.1	32.2	40.3	48.3	64.4	80.5	129	161	242	322
2½	7.6	12.2	15.3	22.9	30.6	38.2	45.8	61.1	76.4	122	153	229	306
2⅝	7.2	11.6	14.5	21.7	29.0	36.3	43.5	58.0	72.5	116	145	218	290
2¾	6.9	11.1	13.9	20.8	27.8	34.7	41.7	55.6	69.5	111	139	208	278
2⅞	6.6	10.5	13.2	19.8	26.4	33.0	39.6	52.8	66.0	106	132	198	264
3	6.3	10.1	12.7	19.1	25.5	31.8	38.2	50.9	63.7	102	127	191	254
3⅛	6.1	9.7	12.2	18.3	24.4	30.5	36.6	48.8	61.0	97.6	122	183	244
3¼	5.8	9.4	11.7	17.6	23.5	29.4	35.3	47.0	58.8	94.0	118	176	236
3⅜	5.6	9.0	11.3	16.9	22.6	28.3	33.9	45.2	56.5	90.4	113	170	226
3½	5.4	8.5	10.9	16.4	21.8	27.3	32.7	43.7	54.6	87.3	109	164	218
3⅝	5.2	8.4	10.5	15.7	21.0	26.3	31.5	42.0	52.5	84.0	105	158	210
3¾	5.1	8.1	10.2	15.3	20.4	25.5	30.6	40.7	50.9	81.5	102	153	204
3⅞	4.9	7.9	9.8	14.8	19.7	24.6	29.6	39.4	49.3	78.8	98.5	148	197
4	4.7	7.6	9.5	14.3	19.1	23.9	28.7	38.2	47.7	76.4	95.5	143	191

Speeds and Feeds

The following threading speeds can be used with either tap or die as a working basis. These speeds will have to be varied to suit the job.

Cast and Malleable Iron and Screw Stock

Diam. in Inches	Surface Feet	R.P.M.
$\frac{1}{8}$	40	1,222
$\frac{3}{16}$	40	814
$\frac{1}{4}$	40	611
$\frac{5}{16}$	40	490
$\frac{3}{8}$	35	356
$\frac{7}{16}$	35	305
$\frac{1}{2}$	35	267
$\frac{9}{16}$	35	240
$\frac{5}{8}$	35	210
$\frac{11}{16}$	35	195
$\frac{3}{4}$	35	178
$\frac{13}{16}$	35	165
$\frac{7}{8}$	35	153
$\frac{15}{16}$	30	122
1	30	115
$1\frac{1}{4}$	30	92
$1\frac{1}{2}$	30	76
2	25	48

Threading Speeds—Brass

$\frac{1}{8}$	135	4,126
$\frac{3}{16}$	135	2,750
$\frac{1}{4}$	125	1,909
$\frac{5}{16}$	125	1,528
$\frac{3}{8}$	120	1,222
$\frac{1}{2}$	120	917
$\frac{5}{8}$	120	715
$\frac{3}{4}$	115	586
1	110	420
$1\frac{1}{4}$	100	306
$1\frac{1}{2}$	90	229
2	85	162

Aluminum

120 surface feet per minute

TABLE 9.—THREADING SPEEDS FOR HIGH-SPEED STEEL CHASERS
For Carbon Steel Chasers Use 60 Per Cent of This Speed
(Geometric Tool Co.)

Material	Surface Speeds for Threads Per Inch		
	3½–7½	8–11	12–32
Tool steel	5	8	10
Vanadium steel—monel metal—nickel steel—forged steel—open hearth	10	15	20
Bessemer screw stock—tobin bronze—drawn steel—machine steel	20	30	50
Cast iron—malleable iron	25	50	80
Copper—phosphor bronze	40	80	150
Cast brass—bar brass—rubber fiber—aluminum—lead	50	100	200

In some cases they can be increased if the metal is free-cutting; in other cases they will have to be reduced because of the opposite condition, but they serve as a very good basis.

In tests, ⅞-inch drills have been run up to 99 feet per minute, in cast iron, with feeds up to 0.104 inch per revolution, removing nearly 12 pounds of metal per minute; 1¼-inch drills were run 260 feet per minute with a feed of 0.145 inch per revolution, removing 37 pounds of metal per minute. This is drilling at the rate of 116 inches per minute. In machinery steel, the speed of a 1¼-inch drill was 180 feet per minute, the feed 0.0815 inch per revolution, removing 15.5 pounds of metal and drilling at the rate of 44.8 inches per minute.

Points in Threading on Automatic Screw Machines[1]

The following are some practical points to keep in mind in camming automatics for threading:

1. A job so cammed that the die head must pull the turret along, instead of leading out in front, will cause defective threading.
2. Cams with excessive lead will result in distorted or stripped threads. A correct thread lobe will present the die head to the work with a positive start, then recede slightly and follow up the die head to completion of the thread length.
3. Self-opening die lobes require a dwell at the finish of the lobe to allow the die head to open correctly.
4. With the exception of one make, solid die heads have no allowance for the addition of a bumper spring. Therefore, the die lobe must allow the die head to lead ahead from the start of the rise.

[1] A. Ainsworth.

5. Self-opening die lobes are cammed heavier than those required for solid die threading.

6. Misalignment between the spindle and the turret will usually result in tapered threads.

7. Worn die head parts or bent shanks will also result in a bad thread.

8. Outside trips should be used if incorporated in die head.

9. A solid die head incorporating both bumper spring and adjustments for misalignment of the spindle is highly recommended.

10. Grinds on chasers will greatly affect threads produced.

11. A die lobe designed for use with a solid die head usually will not allow the substitution of a self-opening die head. The cam will contain no dwell at top of lobe and clearances to approaching cross slides are usually insufficient, due to larger diameter of the self-opening die head.

12. A solid die can never be used in conjunction with a die lobe designed for a self-opening head, as no provision is made for a thread-off portion on cam lobe.

13. Threads of coarser pitch require greater allowance when deducting from actual rise for computing rise on a thread lobe as they require more power and are apt to cause belt or clutch slippage.

SPEED OF REAMERS IN SCREW-MACHINE WORK

The Cleveland Twist Drill Company finds the following to be satisfactory in their screw-machine department:

CARBON REAMERS

	Cast Iron	Machinery Steel	Tool Steel	Brass
Cutting speed	30 ft.	30 ft.	15–20 ft.	100 ft.
Feed per revolution:				
¼-inch hole	0.009 in.	0.004 in.	0.004 in.	0.007 in.
1⅛-inch hole	0.023	0.015	0.011	0.015
2-inch hole	0.033	0.020	0.016	0.020

HIGH-SPEED REAMERS

	Cast Iron and Machinery Steel	Tool Steel	Brass
Cutting speed	50–60 ft.	25–30 ft.	130–150 ft.

Feeds the same as given above for carbon tools.

The amount of stock left in hole for reaming is from about 0.004 inch for ¼-inch size to about 0.009 inch for 2-inch size. For intermediate sizes, the speeds and feeds will be approximately proportional to those given.

For commercial automobile steels, in some cases, the speed may be as high as stated for machinery steel. For the best grades of finish, they recommend carbon reamers at very slow speeds, but good commercial finish within acceptable tolerances can be obtained on a production basis using the feeds, speeds, and amount of stock

	Diameter of Stock													
	1/16	3/32	1/8	3/16	1/4	5/16	3/8	7/16	1/2–9/16	5/8–3/4	13/16–1	1 1/16–1 5/16	1 3/8–1 7/8	2–2 1/2
Thickness T	.020	.030	.040	.050	.060	.070	.080	.090	.100	.120	.140	.160	.190	.220
Depth of angle D For brass	.0085	.013	.017	.0215	.0255	.015	.017	.019	.0215	.0255	.0255	.0255	.0255	.0255
Depth of angle D For steel	.0055	.008	.011	.0135	.016	.0095	.011	.012	.0135	.016	.016	.016	.016	.016

mentioned. Soda water is satisfactory as a lubricant except on automatic machines, where a mineral lard oil is used.

It is also important to use the floating toolholder, and they feel that sufficient emphasis is not usually placed on this attachment.

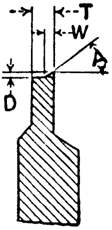
Table of Angles and Thicknesses for Circular Cutting-Off Tools

W is same as T up to 0.060 inch, inclusive.

W is same as one-half T from 0.070 to 0.120 inch thickness, inclusive.

W is 0.060 for 0.140 inch thickness and over.

A is 23 degrees when cutting brass, aluminum, copper, silver, and zinc.



A is 15 degrees when cutting steel, iron, bronze, and nickel.

Least thickness used when cutting off into tapped holes is the lead of two and one-half threads plus 0.010 inch.

Least thickness used when cutting off into reamed holes smaller than 1/8-inch diameter is 0.040 inch.

Thickness used when cutting off tubing is two-thirds T as given for corresponding diameters.

Thickness used when angles or radii start from outside diameter of tool is governed by varying conditions and determined accordingly.

TOLERANCES FOR PIECES MADE IN SCREW MACHINES (OUTSIDE DIAMETERS)

Running Fits not to be Ground

To ½-inch	diam. inclusive	0.0005–0.0015 inch small
To 1-inch	diam. inclusive	0.001 –0.002 inch small
To 2-inch	diam. inclusive	0.0015–0.0025 inch small
To 3½-inch	diam. inclusive	0.0015–0.003 inch small

Standard Fits not to be Ground—All Sizes

Standard to 0.001 inch small

Driving Fits not to be Ground—All Sizes

0.0005 to 0.0015 inch large

Pieces to be Ground—Amount of Stock to be Left for Grinding

To 1-inch	diam. inclusive	0.005–0.007 inch large
To 2-inch	diam. inclusive	0.007–0.010 inch large
To 3½-inch	diam. inclusive	0.010–0.014 inch large

Screw-Machine Limit

Work made on screw machines cannot be made practically to a closer limit than 0.0005 inch either side of a fixed figure (0.001-inch limit). If closer work is required, it must be made large and ground to limit required. If no limit is given on the large part of piece and if not otherwise stated, it can be left stock size.

GRINDING ALLOWANCE FOR BRONZE BUSHINGS (OUTSIDE DIAMETERS)

$$\text{Grind}\left\{\begin{matrix}0.001\text{ inch}\\0.0015\text{ inch}\end{matrix}\right\}\text{Large}$$

Standard Holes (Reamed).—All holes, including parts made in screw machines, unless otherwise specified, are standard diameters. Plugs 0.0005 inch small should go in. Standard plug should wring in. Plugs 0.0005 inch large should not go in.

Operating screws should be ground on the outside diameter of the threaded portion to a limit of Standard to 0.002 inch small.

ESTIMATING SCREW-MACHINE WORK

The accompanying table may be used in connection with the estimating of material required for screw-machine work.

The first column in each division of the table gives the length of the piece plus the width of the cut-off tool. The second column gives the number of pieces per foot of stock length and the third column shows the length of stock required for 1,000 pieces.

While the amount of waste at the end of the bar varies under different conditions, such as size of stock, etc., a fair average of allowance in excess of theoretical lengths is represented by addition of 1½ per cent for small sizes, say, up to ⅝ inch, and about 2 per cent for larger work.

SCREW-MACHINE WORK, NUMBER OF PIECES PER FOOT OF STOCK AND LENGTH OF STOCK FOR 1,000 PIECES

Length, Including Cut-off Tool	Number of Pieces per 1 Foot of Stock	Feet of Stock[1] for 1,000 Pieces	Length Including Cut-off Tool	Number of Pieces per 1 Foot of Stock	Feet of Stock[1] for 1,000 Pieces	Length Including Cut-off Tool	Number of Pieces per 1 Foot of Stock	Feet of Stock[1] for 1,000 Pieces
⅛	96.0	10.5	1⅛	10.66	93.8	2⅛	5.64	177.1
3/16	64.0	15.6	1 3/16	10.1	98.9	2¼	5.33	187.6
¼	48.0	21.0	1¼	9.6	105.8	2⅜	5.05	197.8
5/16	38.4	26.0	1 5/16	9.19	109.4	2½	4.8	211.6
⅜	32.0	31.3	1⅜	8.73	114.5	2⅝	4.57	219.8
7/16	27.4	36.5	1 7/16	8.35	119.7	2¾	4.36	229.0
½	24.0	41.7	1½	8.0	125.0	2⅞	4.17	239.4
9/16	21.3	46.9	1 9/16	7.68	130.2	3	4.0	250.0
⅝	19.2	52.9	1⅝	7.38	135.5	3⅛	3.82	260.4
11/16	17.4	57.3	1 11/16	7.11	140.6	3¼	3.69	271.0
¾	16.0	62.5	1¾	6.85	145.7	3⅜	3.55	281.2
13/16	14.7	67.7	1 13/16	6.62	151.0	3½	3.43	290.4
⅞	13.7	73.0	1⅞	6.4	156.2	3⅝	3.31	302.0
15/16	12.8	78.1	1 15/16	6.19	161.5	3¾	3.2	312.4
1	12.0	83.3	2	6.0	167.0	3⅞	3.09	323.0
1 1/16	11.3	88.5	....	....	....	4	3.0	334.0

[1] Add 1½ per cent for work under ⅝ inch; add 2 per cent for work above ⅞ inches.

STANDARDS FOR ROTATING AIR CYLINDERS AND ADAPTERS, 1932

These standards have been developed to obtain interchangeability of different makes of air cylinders on the spindles of machine tools without changing the adapter or draw rod.

Three sizes of standard adapters cover the complete range of standard air cylinders which range in size from 3 to 18 inches inclusive. Adapter A fits the 3- and 4½-inch cylinders, adapter B fits the 6- and 8-inch cylinders, and adapter C fits all sizes of cylinders from 10 to 18 inches inclusive. A fourth size D is also included to accommodate 20-inch cylinders or other power-operated device having draw-rod pull of 26,000 to 40,000 pounds.

The length of stroke of the standard cylinders, the position of the piston rod at the end of the stroke, the diameter of the piston rod, and the size of the tapped hole in the piston rod have also been standardized so that air-cylinder draw rods do not have to be fitted to individual air cylinders. The strokes are:

3 to 4½-inch cylinder..............	1-inch stroke
6 to 14-inch cylinder..............	1½-inch stroke
16 to 20-inch cylinder..............	2-inch stroke

In order to allow the use of air cylinders on spindles with comparatively small holes, the diameters of the piston rods are as small as is consistent with the requisite strength.

In order to make it easy to compute the lengths of draw rods, the end of the piston rod projects 1 inch beyond the face of the hub on all sizes of air cylinders when the piston is at one end of its stroke and projects 1 inch plus the length of the stroke when the piston is at the other end of the stroke.

The standard adapters are made with hubs large enough to take care of the majority of cases. The piston rods and adapters of this standard have been designed to withstand stress resulting from air pressures up to 100 pound per square inch. It is intended, however, that these pistons and adapters may be applied to hydraulic cylinders or to other mechanical operating devices which do not develop working stresses in excess of those developed by the corresponding sizes of air cylinders.

STEPS IN SCREW-MACHINE CAM DESIGN[1]

1. Draw any vertical line *AB*, Fig. 21, and through its center draw any horizontal line *CD*. The latter represents the center line of the work and spindle. Against *AB* and to the right, draw the finished work, with its small end toward *D*. To the left of *AB* ($\frac{1}{4}$ in. or more) draw parallel line *EF*. This is the face line of the spindle chuck. Extend the largest diameter of the work lines to the left, cutting *EF*. Draw form tool groove *G* in work.

2. Determine the method for machining; whether entirely formed by the front or back tools, and cut off, or if first turned from the turret, and then formed and cut off. This depends upon ratio between width of form cut and work diameter.

3. Determine the cutting travel, or throw, and feed per revolution for the front and back tools; whether these tools must work alone, or if either one or both can start together with a turret tool.

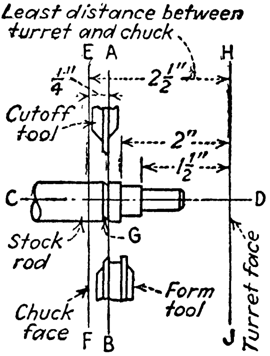


FIG. 21.—Laying Out Cams

4. Select the machine. This involves diameter of stock, length of finished piece, extreme length that can be turned, rigidity of machine for the work, lowest speed of machine (whether it is too fast for threading), greatest length of tools the turret will swing, and the diameter of special tools the turret will swing, if used.

5. Determine the working position of the form and cut-off tools and draw them on the sketch.

6. Draw another vertical line *HJ* to the right of the work, representing the turret face, at the nearest position between turret and chuck, and so dimension it. Add dimensions from the turret face to each shoulder.

7. Determine the revolutions per minute of the spindle, forward and reverse. Reverse is needed only when threading.

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[1] C. W. Hinman.

8. Determine the order of operations. Name each one that requires time to complete, and write them in orderly sequence, one below the other, on a trial layout sheet.

9. Determine the cutting travel or throw for each turret tool. Write these after their respective operations on the trial layout.

10. Select the feed per revolution for each turret tool. Write these after their respective operations.

11. Calculate the number of revolutions for each operation. Revolutions = travel ÷ feed.

12. Complete the trial layout. Estimate about 20 revolutions for each operation of indexing and to feed the stock, then total with all the machining operations. Compare the total revolutions with the table[1] of actual number of revolutions to make one piece on the machine selected. Choose the next higher number in the table, and substitute it on the layout. Also determine from the table the exact number of revolutions for feeding and indexing, and substitute. Spread the extra revolutions, if any, on the heaviest cuts, and recalculate the feeds. The total number of revolutions must equal the actual number of revolutions chosen.

13. Determine from the table the time in seconds to make one piece and select the change gears.

14. Insert the number of hundredths of cam surface for each operation. The number of hundredths is found by dividing the number of revolutions for the operation by the actual number of revolutions to make one piece, with two places pointed off from the right.

15. Total divisions must be 100.

16. Finish the layout, allowing for dwells and tool clearances. When using the slotting arm, one turret hole, previous to feeding, must be vacant to clear the arm.

17. Determine where the form and cut-off tools are to begin and end their work. The cutting-off lobe usually ends at 99½.

18. There should be from 5 to 7 hundredths cam clearance between all large turret tools and the cross-slide front or back tools, if either of the latter follow next.

19. Draw the cams from the layout, cutting down the heights of the lead cam lobes, if necessary, to suit the tool body lengths (plus ¼ in.) as compared with the shoulder dimensions in the sketch. Lobes on front and back cams are usually the same height as the cam-blank radius.

20. There should be sufficient time to index the turret past its idle holes while cutting off. Example: For Brown and Sharpe No. 0 machine, it requires ⅝ second to feed stock or to revolve the turret once. If the spindle speed is 1,207 revolutions per minute, it will require 13 revolutions to index once; 26, twice; and 39, three times.

21. Check the feeding distance for the extreme length of the feed for one throw of the feeding finger.

22. When right-handed threading is performed, the fast speed of the spindle will be backward, and the slow forward. For left-handed threading, conditions are reversed.

23. The number of revolutions for threading off is the same as the number of threads in the length to be threaded plus 4.

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[1] This refers to the tables in Brown and Sharpe screw-machine treatise.

24. Number of revolutions for threading on in the layout is the number for threading off, multiplied by the ratio found by dividing the fast spindle speed by the slow.

25. If taps are coarser than 18 pitch and dies coarser than 16 pitch, for screw stock, provide two threading lobes, one for roughing and one for finishing. On tool steel, the same applies to taps coarser than 24 pitch and to dies coarser than 20 pitch.

26. Check the threading operation, whether a releasing or a nonreleasing holder is required.

THREAD LOBES FOR SCREW MACHINE CAMS[1]

The following five methods show the difference in required die-lobe rises on Brown and Sharpe cams for a screw threaded for a distance of 0.875 inch at forty threads per inch, with a self-opening die head. Each method results in the same ultimate thread.

1. A die lobe representing the exact duplication of a lead screw in an engine lathe; a 40-pitch thread advances 0.025 inch per revolution of spindle or part. $\left(\frac{1.000}{40} = 0.025.\right)$ Thread length of $\frac{7}{8}$ inch equals 35 revolutions. $\left(\frac{40 \times 7}{8} = 35 \text{ rev.}\right)$ To this add three revolutions for approach to the work, making a total of 38 revolutions to thread the part. Multiply the 38 revolutions by the 0.025 inch rise per revolution to determine that 0.950 inch die lobe rise is required.

2. The general recommendation of self-opening die head manufacturers is the actual lead as shown by method 1, plus 5 per cent. Required die lobe rise is then 0.950 inch times 1.05, or 0.997 inch die lobe rise.

3. Another principle holds that the die head must advance 12.5 per cent ahead of lead on the cam as compiled by actual required lead on the part to be threaded. After this is determined, divide results of 12.5 per cent less than actual lead into the length of thread required. This result equals actual revolutions required to complete the thread. To this add four revolutions for approach and the total number of revolutions is determined. To find the required die lobe rise multiply the actual $\frac{1}{8}$ lead by the total revolutions and then subtract 10 per cent. Converting this into figures we find that a lead of 0.025 minus 12.5 per cent equals 0.022 inch lead. A threaded portion of 0.875 inch divided by 0.022 inch lead equals 39 revolutions. This plus four revolutions for approach equals 43 required revolutions of spindle to complete the thread; multiply 43 revolutions by 0.022 lead equals 0.946 inch rise; this less 10 per cent equals 0.852 inch—the required die lobe rise.

4. By a fourth method the following information must be known: (*a*) Actual number of revolutions required to thread; (*b*) 10 per cent of this figure to add for approach; (*c*) ratio between threading and cutting spindle speeds; (*d*) complete machine cycle time to produce one part; (*e*) spindle speeds at which job is to be run; (*f*) die lobe revolutions converted into hundredths of cam space, and,

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[1] A. Ainsworth.

(*g*) revolutions of spindle per hundredths of cam space at threading spindle revolutions per minute.

Then ⅞ inch of 40 threads per inch thread requires 35 revolutions; adding 10 per cent, this equals 39 revolutions; multiplied by ratio of difference between spindle speeds (1,474 revolutions per minute divided by 663) or 39 × 2.22 equals 86 revolutions. With a known machine index time of 18⅓ seconds we can determine the total revolutions at 1,474 revolutions per minute to complete the job and determine the hundredths of cam space required to thread. Converted, this is 18⅓ seconds at 1,474 revolutions or 450 revolutions (4.5 revolutions per 0.01 of cam space). Thus 86 revolutions are required to complete the thread, therefore 86 total revolutions divided by 4.5 equals 0.19 of cam space required to thread. Converted into revolutions at threading spindle speed the 450 revolutions required equal 205 or 2.05 revolutions per cam space.

The formula then used is: Pitch in thousandths × revolutions per cam space at threading spindle speed × cam space to thread in hundredths = the required die lobe rise.

Numerically this is: $\frac{6.000}{40} \times 2.05 \times 19 = 0.973$ inch required die lobe rise.

5. Another widely used formula is:

$$\text{Die lobe rise} = \frac{\text{revolutions required to thread}}{\text{number of threads per inch}} \times \left\{\begin{array}{l}\text{a variable constant for}\\ \text{groups of threads}\\ \text{known as } A \text{ and } B.\end{array}\right.$$

$A = 0.85$ for 14 to 24 threads per inch.
$B = 0.88$ for 28 to 48 threads per inch.

Translated to our example this is $\frac{38}{40} \times 0.88 = 0.836$ inch required die lobe rise.

Methods 1, 2, and 4 Recommended

In checking the figures shown in Table 9*a*, it will be noted that method 3 shows a higher cam lobe to thread than method 5. However, the former method allows more revolutions to thread and when proportioned out to equal advance per revolution it is found to be less than No. 5. This means that the thread in method 3 will cover more cam space, but will have less lead on the lobe as compared with No. 5.

A self-opening die head has a bumper spring which allows lead on the cam either to equal or to exceed the advance of die head per work spindle revolution. Another die head feature compensates for worn index parts to eliminate variances in thread length. This is the outside trip. When a cam is designed to equal or exceed required lead, the outside trip will assure equal threaded lengths regardless of machine wear.

TABLE 9a.—RESULTS OF THREAD LOBE RISE CALCULATIONS BY THE FIVE METHODS DESCRIBED
(Figured for Self-Opening Die Heads)

Method	Req. Rev. to Thread	Req. Die Rise Lobe	Die Head Adv. per Spindle Rev.	Lgth. of Thd. Portion	Threads per Inch
[1]1	38	0.950	0 025	0.875	40
[1]2	38	0.997	0.026	0.875	40
3	43	0.852	0.019	0.875	40
[1]4	39	0.973	0.025	0.875	40
5	38	0.836	0 022	0.875	40

[1] Recommended.

TABLE 9b.—VARIATION IN THREAD LOBE RISE CALCULATIONS BY THE FIVE METHODS
(Applied to Cams for Use on Solid Die Heads)

Method	Req. Rev. to Thread	Req. Die Rise Lobe	Die Head Adv. per Spindle Rev.	Lgth. of Thd. Portion	Threads per Inch
1	38	0.950	0.025	0.875	40
2	38	0.997	0.026	0.875	40
[1]3	43	0.852	0.019	0.875	40
4	39	0.876	0.0225	0.875	40
[1]5	38	0.753	0.0198	0.875	40

[1] Recommended.

Experience recommends that method 1, 2 or 4 be used to determine self-opening die thread lobes.

With solid dies, where the die must be threaded on and off the work, different factors must be taken into consideration. The die head must lead on the thread-on and thread-off portion of the lobe, as faulty threads may be produced during either operation. Generally speaking there is no bumper or compensating spring in solid die heads, thus the lead on the die lobe must permit a slight lead off from the start. However, too much lead would result in the die head pulling out to its extreme and causing stripped threads, as the die head pulls the turret forward, rather than the cam pushing the turret forward. On the thread-off operation the same difficulties are encountered. An incorrect thread-off lobe will cause the turret to pull the die head off. This is caused by the cam dropping away too quickly. Crowding of die head back into the holder before it is clear of work is caused by a cam designed with drop away too slow. Either condition results in poor threads.

A cam lobe for a solid die head requires more care and consideration than is required for the construction of one for a self-opening die.

Reviewing the requirements of the two types of die heads we find that the first two methods of determining the thread lobe rise cannot be applied to calculations for the solid die heads.

Method 3.—This is entirely satisfactory for solid die-head lobe construction, but care must be taken to use the extra revolutions, which require more cam space and thereby decrease the actual lead on the cam.

In applying method 4, take this same formula and use only 90 per cent of the die lobe rise computation obtained. On the example used this would result in a die lobe rise of 0.876 inch.

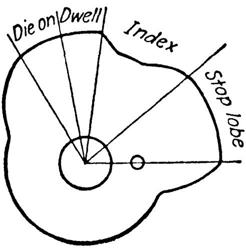


FIG. 22.

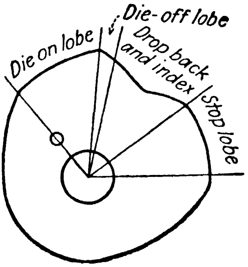


FIG. 23.

FIG. 22.—Cam for Self-Opening Die Head Showing the Lobe and Dwell. The Part for Which This Was Designed Is Identical with That to Be Reproduced by the Cam in Fig. 23. Index Cycle Time Is 3 Seconds and Spindle Speed Is 600 to 1,200 Revolutions per Second.

FIG. 23.—Cam for Solid Die Head to Be Used in Producing the Same Part as That Resulting from the Use of the Cam in Fig. 22 with a Self-Opening Die Head. The Same Cycle and Same Spindle Speeds Are Used in Both Instances.

Method 5. The use of this method will, of course, result in the same calculation as for the self-operating die lobe, or a required die lobe rise of 0.836. Experience has shown that the use of this method, with a further reduction of from 8 to 10 per cent on the results of its calculation, produces a desirable thread lobe for solid die head threading. On the example shown this would mean a required die lobe rise of approximately 0.753 inch. Figures 22 and 23 show cams for both types of dies.

KNURLING TOOLS FOR AUTOMATICS

A simple method of knurling on Brown and Sharpe automatics, as to setting up, adjustment, and cam design, for plain parts, is as shown in Figs. 24 and 25 with side knurl holders where there is no need of turret tools. With a turret support, Fig. 26, wide knurling can be done. A. Ainsworth points out, however, that considerable side pressure results from this method of knurling, and that it is advisable to use light feeds and to provide for a dwell at the end of the cam rise. The side knurl holder is a circular disk similar to a cross slide circular tool. Mounted into the face of this holder is a single or double knurl rotating on ground steel pins.

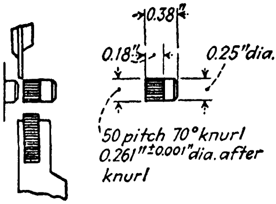


FIG. 24.

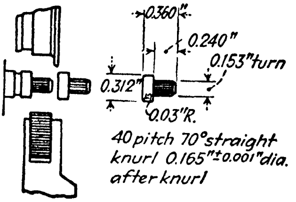


FIG. 25.

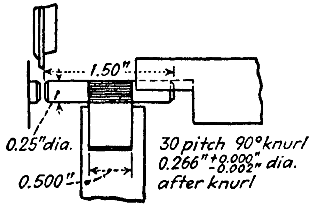


FIG. 26.

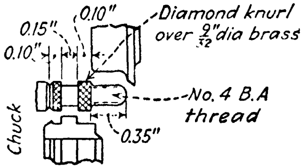


FIG. 27.

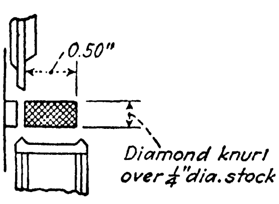


FIG. 28.

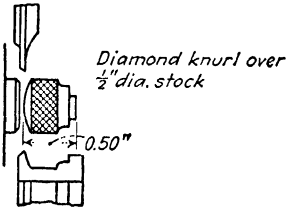


FIG. 29.

FIGS. 24 to 29.—Knurling Tools for Automatics.

Five types of tool holders are seen in Figs. 35 to 39. A very versatile type is shown in Fig. 37. It can be used to produce straight, diamond, or helical knurled diameters with a pair of straight knurls, by adjusting the knurls in their blocks. It can be fed at a much greater rate than the cross slide types. Side pressure is eliminated, but it requires knurling both on and off the work. The off-feed, however, is double that of the on-feed. As a result, the cam lobe for turret knurling closely resembles a solid threading die lobe and is often confused with it.

This method of knurling can be used when cross slide tool holders are required for other tools. Cam design and setup are rather simple, and faster feeds and lower clearance requirements often lead to its choice over swing-knurling. Use of the turret knurl eaves the cross slide to remove the burr.

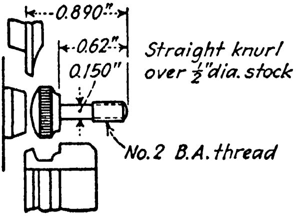


FIG. 30.

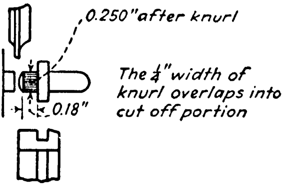
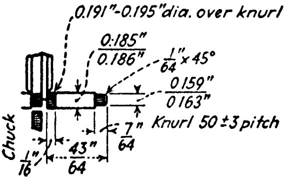


FIG. 31.



Knurl from front side

FIG. 32.

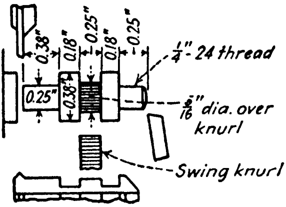


FIG. 33.

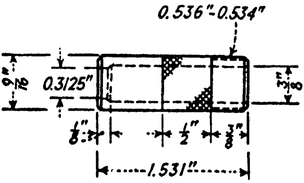


FIG. 34.

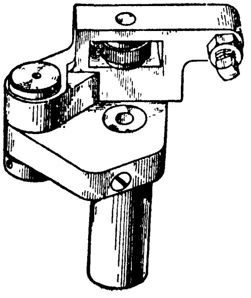


FIG. 35.

FIGS. 30–35.—Knurling Tools for Automatics.

After one piece of work has been severed from the bar (Fig. 27), the combination cut-off and form tool drops back to allow threading and knurling, then again approaches the work to remove the burr. Again dropping away, the cam allows the finished piece to be fed to length and the cut-off tool approaches to sever the part.

A second method is shown in Fig. 28. Here knurling is over stock diameter and requires no forming to size. The form tool is designed either to break corners or to produce a chamfer, as required. Fig. 29 illustrates the third method. This can be applied where the length of the part is not prohibitive. The part is knurled over its entire length. The form tool immediately follows the knurling operation and removes the knurl wherever it is not required.

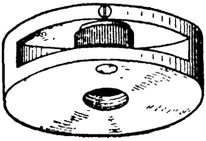


FIG. 36.

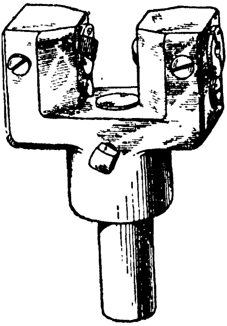


FIG. 37.

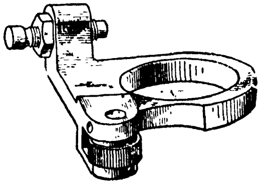


FIG. 38.

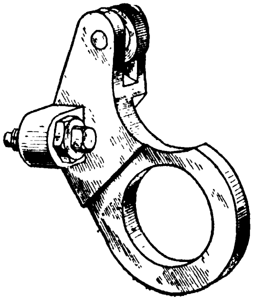


FIG. 39.

FIGS. 36–39.—Knurling Tools for Automatics.

Figure 30 shows another type of knurling which can be done with the adjustable turret method. By forming or box-tooling previous to the knurling operation, much machine time is saved, as it is not necessary to knurl the entire length of the part. This may be used when the diameter to be knurled is larger than any other diameter over which the knurl must pass to reach the starting point.

The use of top and bottom knurl holders for cross slides is similar in principle to the use of a side knurl holder. A hub is ground on the circular tool and the knurl inserted over this and clamped into the cross slide tool post, together with the circular tool. An adjusting screw permits the knurl to be set as required.

This method is applied when all the turret positions are close to other necessary tools or where no other turret tools would be required, provided that the part can be top and bottom knurled. It can be applied only when the required knurled width does not exceed that of standard knurls mounted in holder (Fig. 31). It cannot be used where the required knurl is close to either form or cut-off tool.

In Fig. 32 it can be seen that a top knurl holder is used in conjunction with a combination cut-off and form tool and a side knurl holder. The part is fed to length into a combined stop and support. The combination cut-off and form tool, which contains top knurl, advances and knurls the large diameter. Passing over the top of the bar, the knurl loses contact and the cut-off tool severs one piece and finish forms the next. Drop back on the cam allows this holder to clear the side knurl holder, advancing to knurl the small diameter. At the completion of this knurl the cut-off tool again returns to remove the burr. This fourth method requires somewhat complicated camming. Provision must be made for approach of the knurl before the cross slide can feed the knurl into the work. At completion of knurling, extra clearance must be provided to assure the cross slide clearing away before the swing knurl can be indexed out of position.

Figures 33 and 34 show two types of work that can be done more easily, or only, by the swing tool method. The knurl in Fig. 33 could be done only in this way, while the operation in Fig. 34, if done by side knurling, would require the use of special width knurls. In turret swing knurling on this job, a $\frac{1}{4}$ inch wide knurl is fed into the bar by cross slide and then allowed to dwell while the turret advances the knurl along the bar to complete the knurled width required.

In swing turret knurling, a guide is required to replace the regular raising block on right-hand cutting jobs. When a left-hand spindle direction is required, no block can be inserted under the front cross slide if a cutting tool is to be applied in this position; a special guide is installed by bolting to the side of the toolholder.

AMERICAN STANDARD CIRCULAR AND DOVETAIL FORMING TOOL BLANKS OCTOBER, 1943

This standard covers sizes and types of circular and dovetail forming tool blanks for automatic screw machines. The purpose is to provide interchangeability and to permit the reduction of the number of blanks now in use.

In order to establish a minimum number of blank sizes, the machines have been classified, for reference purposes, into six different groups of comparable stock capacities. Each group of machines takes a definite size of tool. The group-numbers have been arbitrarily assigned to identify the size of tool with the machines in which it is used.

The illustrations and dimensions of the different designs have been separated from the machine classification in order that in the

TABLE 10.—MACHINE CLASSIFICATION
(Dimensions in Inches)

Group Number	Type of Machine	Maximum Capacity[1]	Group Number	Type of Machine	Maximum Capacity[1]
1	No. 00 Brown and Sharpe	⅜	4	1⅝ Gridley	1⅝
	No. 19 Brown and Sharpe	⅜		1⅝ Acme Gridley	1⅝
	Index "o"	7/16		No. 206 New Britain	1⅝
	⅜ Cleveland	⅝		No. 415 New Britain	1⅝
2	⅜ Gridley	⅜		No. 410 New Britain	
	½ Davenport	⅞		1¾ Gridley	1¾
	9/16 Acme Gridley	9/16		1¾ Greenlee	1¾
	No. 0 Brown and Sharpe	⅝		No. 4 Brown and Sharpe	1⅞
	⅝ Cleveland	¾		2 Greenlee	2
	⅝ × ⅞ Cleveland	1 1/16		2 Gridley	2
	No. 204 New Britain	⅝		2 Cleveland	2½
	⅞ Greenlee	1		2 × 2¾ Cleveland	3¼
	⅞ × 1¼ Cleveland	⅞		2¼ Cleveland	2½
3	⅞ Gridley	⅞		2¼ × 2¾ Cleveland	3¼
	1 Acme Gridley	1		2¼ Gridley	2¼
	No. 172 New Britain	1		2¼ Greenlee	2¼
	No. 2 Brown and Sharpe	1⅛	5	No. 6 Brown and Sharpe	2⅜
	1¼ Gridley	1¼		No. 208 New Britain	2½
	1¼ Cleveland	1¼		No. 425 New Britain	2½
	1¼ Cleveland	1⅜		2⅝ Gridley	2⅝
	1¼ × 1½ Cleveland	1¼		2¾ × 3¾ Cleveland	3¼
	1¼ × 1½ Cleveland	1½		2¾ × 4 Cleveland	2¾
	1¼ Greenlee	1¼		3 Gridley	3
	1⅜ Gridley	1⅜		3 5/16 Gridley	3 5/16
	1½ Greenlee	1½	6	3¼ Gridley	3¼
	1⅝ Gridley	1⅝		3½ Gridley	3½
				4 Gridley	4
				4 Cleveland	4
				4¼ Cleveland	4½
				4¼ Cleveland	4¼
				4¼ Gridley	4¼
				4½ Gridley	4½
				5 Gridley	5
				5½ Cleveland	5½
				6¾ Cleveland	6¾
				7¾ Cleveland	7¾

[1] The group classification numbers apply to all machine models of the respective makes listed having the maximum capacities indicated.

future new models of machines may be introduced into the respective groups without affecting the standardization of tool blanks.

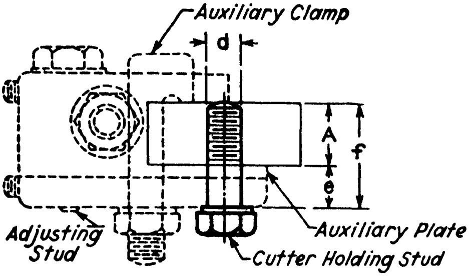
To facilitate procurement of tool blanks from commercial sources, circular tools have been designated by outside diameter and width of tool blanks and dovetail tools by group number and width of tool blank.

Circular Tool Blanks

A circular tool blank is a disk with a centrally located mounting hole, plain or threaded, and a number of adjusting holes in the side. Circular blanks are used for making forming and cut-off tools by machining the periphery to the form of the product to be made. A notch is ground in the periphery to provide a cutting edge.

Dovetail Tool Blanks

A dovetail tool blank is a square or rectangular block having an external dovetail machined on one side throughout its whole length for clamping in the toolholder. The dovetail is slotted to provide adjustment. Dovetail blanks are used for making forming and cutting-off tools by machining the desired formed profile in the side opposite the dovetail and throughout its entire length. The top of the formed section is the cutting edge.



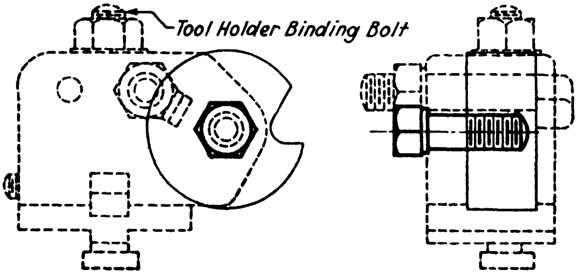


TABLE 11.—TYPICAL CIRCULAR FORMING TOOL HOLDER FOR MACHINES IN GROUP I
(Dimensions in Inches)

Machine Group Number	Width of Blank	Bolt		Tool Post
		Length	Thread Size	
	A	*f*[1]	*d*[2]	*e*
I	$\frac{1}{4}$ $\frac{3}{8}$ $\frac{1}{2}$ $\frac{3}{4}$ 1	$\frac{3}{4}$ $\frac{7}{8}$ 1 $1\frac{1}{4}$ $1\frac{1}{2}$	$\frac{3}{8}$ to 16 $\frac{3}{8}$ to 16 $\frac{3}{8}$ to 16 $\frac{3}{8}$ to 16 $\frac{3}{8}$ to 16	$\frac{7}{16}$ $\frac{7}{16}$ $\frac{7}{16}$ $\frac{7}{16}$ $\frac{7}{16}$

Tolerance for dimensions not otherwise specified shall be held to ± 0.010.

[1] Tolerance for length of bolt is ± $\frac{1}{32}$.

[2] Screw thread shall be made to Class 2 (NC 2, ASA B1.1-1935).

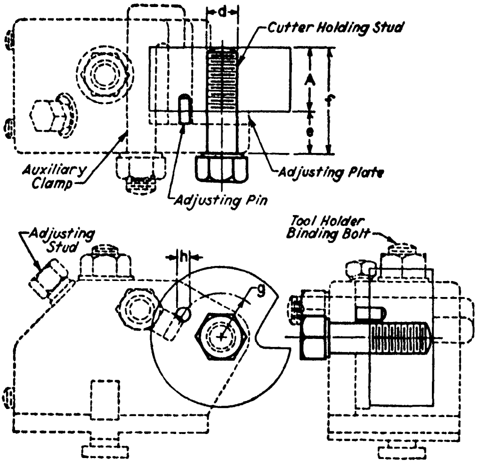


TABLE 12.—TYPICAL CIRCULAR FORMING TOOL HOLDER FOR MACHINES IN GROUPS 2 AND 3
(Dimensions in Inches)

Machine Group Number	Width of Blank	Bolt		Adjusting Pin		Tool Post
		Length[1]	Thread Size[2]	Radius[3]	Diameter[4]	
	A	*f*	*d*	*g*	*h*	*e*
2	3/8	1 1/8	1/2-13	11/16	0.185	3/4
	1/2	1 1/4	1/2-13	11/16	0.185	3/4
	3/4	1 1/2	1/2-13	11/16	0.185	3/4
	1	1 3/4	1/2-13	11/16	0.185	3/4
	1 1/4	2	1/2-13	11/16	0.185	3/4
3	1/2	1 3/8	5/8-11	3/4	0.185	13/16
	3/4	1 5/8	5/8-11	3/4	0.185	13/16
	1	1 7/8	5/8-11	3/4	0.185	13/16
	1 1/4	2 1/8	5/8-11	3/4	0.185	13/16
	1 1/2	2 3/8	5/8-11	3/4	0.185	13/16

Tolerances for dimensions not otherwise specified shall be held to ±0.010.

[1] Tolerance for length of bolt is ± 1/32.

[2] Screw thread *d* shall be made to Class 2 (NC 2, ASA B1.1-1935).

[3] Tolerance for the radius of the adjusting pin *g* is ±0.001.

[4] Tolerance for the diameter of the pin is +0.000 −0.001.

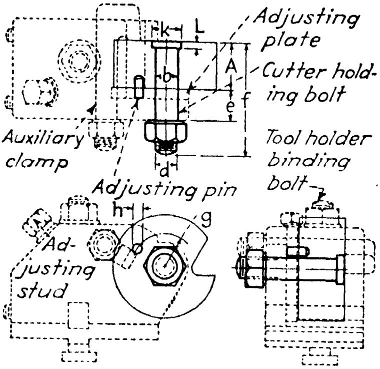


TABLE 13.—TYPICAL CIRCULAR FORMING TOOL HOLDER FOR MACHINES IN GROUPS 4, 5, AND 6
(Dimensions in Inches)

Machine Group Number	Width of Blank	Bolt					Adjusting Pin		Tool Post
		Length[1]	Thread[2]	Body[3]	Head		Radius[4]	Diameter[5]	
	A	f	d	b	k	L	g	h	e
4	$\frac{1}{2}$	$2\frac{1}{2}$	$\frac{3}{4}$–10	0.749	1	$\frac{1}{4}$	$\frac{15}{16}$	0.248	$1\frac{1}{8}$
	$\frac{3}{4}$	$2\frac{3}{4}$	$\frac{3}{4}$–10	0.749	1	$\frac{1}{4}$	$\frac{15}{16}$	0.248	$1\frac{1}{8}$
	1	$2\frac{3}{4}$	$\frac{3}{4}$–10	0.749	1	$\frac{1}{4}$	$\frac{15}{16}$	0.248	$1\frac{1}{8}$
	$1\frac{1}{2}$	$3\frac{1}{2}$	$\frac{3}{4}$–10	0.749	1	$\frac{1}{4}$	$\frac{15}{16}$	0.248	$1\frac{1}{8}$
	2	$3\frac{1}{2}$	$\frac{3}{4}$–10	0.749	1	$\frac{1}{4}$	$\frac{15}{16}$	0.248	$1\frac{1}{8}$
	$2\frac{1}{2}$	$3\frac{1}{2}$	$\frac{3}{4}$–10	0.749	1	$\frac{1}{4}$	$\frac{15}{16}$	0.248	$1\frac{1}{8}$
5	$\frac{5}{8}$	3	1– 8	0.999	$1\frac{5}{16}$	$\frac{5}{16}$	$1\frac{1}{16}$	0.310	$1\frac{3}{8}$
	1	$3\frac{1}{4}$	1– 8	0.999	$1\frac{5}{16}$	$\frac{5}{16}$	$1\frac{1}{16}$	0 310	$1\frac{3}{8}$
	$1\frac{1}{2}$	$3\frac{1}{4}$	1– 8	0.999	$1\frac{5}{16}$	$\frac{5}{16}$	$1\frac{1}{16}$	0.310	$1\frac{3}{8}$
	2	$4\frac{1}{4}$	1– 8	0.999	$1\frac{5}{16}$	$\frac{5}{16}$	$1\frac{1}{16}$	0.310	$1\frac{3}{8}$
	$2\frac{1}{2}$	$4\frac{1}{2}$	1– 8	0 999	$1\frac{5}{16}$	$\frac{5}{16}$	$1\frac{1}{16}$	0.310	$1\frac{3}{8}$
	3	$4\frac{1}{2}$	1– 8	0.999	$1\frac{5}{16}$	$\frac{5}{16}$	$1\frac{1}{16}$	0.310	$1\frac{3}{8}$
6	$\frac{5}{8}$	$3\frac{1}{4}$	1– 8	0.999	$1\frac{5}{16}$	$\frac{5}{16}$	$1\frac{1}{16}$	0.310	$1\frac{3}{8}$
	1	$3\frac{3}{4}$	1– 8	0.999	$1\frac{5}{16}$	$\frac{5}{16}$	$1\frac{1}{16}$	0.310	$1\frac{3}{8}$
	$1\frac{1}{2}$	$3\frac{3}{4}$	1– 8	0.999	$1\frac{5}{16}$	$\frac{5}{16}$	$1\frac{1}{16}$	0.310	$1\frac{3}{8}$
	2	$4\frac{3}{4}$	1– 8	0.999	$1\frac{5}{16}$	$\frac{5}{16}$	$1\frac{1}{16}$	0.310	$1\frac{3}{8}$
	3	$4\frac{3}{4}$	1– 8	0.999	$1\frac{5}{16}$	$\frac{5}{16}$	$1\frac{1}{16}$	0.310	$1\frac{3}{8}$
	4	$4\frac{3}{4}$	1– 8	0.999	$1\frac{5}{16}$	$\frac{5}{16}$	$1\frac{1}{16}$	0.310	$1\frac{3}{8}$

Tolerance for dimensions not otherwise specified shall be held to ±0.010.

[1] Tolerance for length of bolt f is $\pm\frac{1}{32}$.

[2] The screw thread d shall be made to Class 2 (NC 2, ASA B1.1–1935).

[3] The body of the screw b shall have a tolerance of $+0.000$, -0.001.

[4] Tolerance for the radius of the adjusting pin g is ± 0.001.

[5] Tolerance for the diameter of the adjusting pin h is $+0.000$, -0.001.

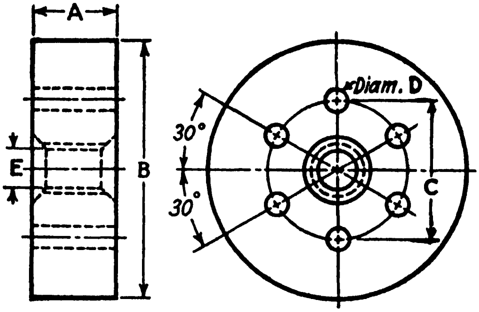


TABLE 14.—DIMENSIONS FOR FINISHED BLANKS FOR CIRCULAR FORMING TOOLS WITH THREADED MOUNTING HOLE

(Dimensions, except pitch, in inches)

Group Number	Basic Blank Size[1]	Diameter B		Width A		Adjusting Holes[3]		Diam. of Threaded Hole[6] E	Pitch of Threaded Hole[6] E
		Max.	Min.	Max.	Min.	C[5]	D[4]		
1	$1\frac{3}{4} \times \frac{1}{8}$	$1\frac{25}{32}$	$1\frac{49}{64}$	$\frac{5}{32}$	$\frac{9}{64}$	No pin hole		$\frac{3}{8}$	16
	$1\frac{3}{4} \times \frac{3}{8}$	$1\frac{25}{32}$	$1\frac{49}{64}$	$\frac{13}{32}$	$\frac{25}{64}$			$\frac{3}{8}$	16
	$1\frac{3}{4} \times \frac{1}{2}$	$1\frac{25}{32}$	$1\frac{49}{64}$	$\frac{17}{32}$	$\frac{33}{64}$			$\frac{3}{8}$	16
	$1\frac{3}{4} \times \frac{3}{4}$	$1\frac{25}{32}$	$1\frac{49}{64}$	$\frac{25}{32}$	$\frac{49}{64}$			$\frac{3}{8}$	16
	$1\frac{3}{4} \times 1$	$1\frac{25}{32}$	$1\frac{49}{64}$	$1\frac{1}{32}$	$1\frac{1}{64}$			$\frac{3}{8}$	16
2	$2\frac{1}{4} \times \frac{3}{8}$	$2\frac{9}{32}$	$2\frac{17}{64}$	$\frac{13}{32}$	$\frac{25}{64}$	$1\frac{3}{8}$	$\frac{3}{16}$	$\frac{1}{2}$	13
	$2\frac{1}{4} \times \frac{1}{2}$	$2\frac{9}{32}$	$2\frac{17}{64}$	$\frac{17}{32}$	$\frac{33}{64}$	$1\frac{3}{8}$	$\frac{3}{16}$	$\frac{1}{2}$	13
	$2\frac{1}{4} \times \frac{3}{4}$	$2\frac{9}{32}$	$2\frac{17}{64}$	$\frac{25}{32}$	$\frac{49}{64}$	$1\frac{3}{8}$	$\frac{3}{16}$	$\frac{1}{2}$	13
	$2\frac{1}{4} \times 1$	$2\frac{9}{32}$	$2\frac{17}{64}$	$1\frac{1}{32}$	$1\frac{1}{64}$	$1\frac{3}{8}$	$\frac{3}{16}$	$\frac{1}{2}$	13
	$2\frac{1}{4} \times 1\frac{1}{4}$	$2\frac{9}{32}$	$2\frac{17}{64}$	$1\frac{9}{32}$	$1\frac{17}{64}$	$1\frac{3}{8}$	$\frac{3}{16}$	$\frac{1}{2}$	13
3	$3 \times \frac{1}{2}$	$3\frac{1}{32}$	$3\frac{1}{64}$	$\frac{17}{32}$	$\frac{33}{64}$	$1\frac{1}{2}$	$\frac{3}{16}$	$\frac{5}{8}$	11
	$3 \times \frac{3}{4}$	$3\frac{1}{32}$	$3\frac{1}{64}$	$\frac{25}{32}$	$\frac{49}{64}$	$1\frac{1}{2}$	$\frac{3}{16}$	$\frac{5}{8}$	11
	3×1	$3\frac{1}{32}$	$3\frac{1}{64}$	$1\frac{1}{32}$	$1\frac{1}{64}$	$1\frac{1}{2}$	$\frac{3}{16}$	$\frac{5}{8}$	11
	$3 \times 1\frac{1}{4}$	$3\frac{1}{32}$	$3\frac{1}{64}$	$1\frac{9}{32}$	$1\frac{17}{64}$	$1\frac{1}{2}$	$\frac{3}{16}$	$\frac{5}{8}$	11
	$3 \times 1\frac{1}{2}$	$3\frac{1}{32}$	$3\frac{1}{64}$	$1\frac{17}{32}$	$1\frac{33}{64}$	$1\frac{1}{2}$	$\frac{3}{16}$	$\frac{5}{8}$	11

[1] Blanks are designated by the basic outside diameter and width. Blanks made of high-speed steel shall be stamped H.S.

[2] Six adjusting holes shall have a minimum depth of $\frac{1}{4}$ inch, greater depth or through holes optional. Adjusting holes shall be equally spaced on the C diameter circle and slightly chamfered.

[3] Diameter C of location circle shall be ± 0.002.

[4] Diameter of adjusting holes D shal be ± 0.002.

[5] The threaded hole E shall be held within Class 2 tolerances (NC 2, ASA B1.1–1935. Both ends of threaded hole E shall be chamfered 35 degrees.

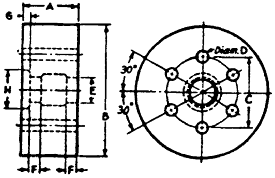


TABLE 15.—DIMENSIONS FOR FINISHED BLANKS FOR CIRCULAR FORMING TOOLS WITH COUNTERBORED MOUNTING HOLE

(Dimensions in Inches)

Group Number	Basic Blank Size[1]	Diameter B		Width A		Adjusting Holes[2]		Mounting Hole			
								Diameter	Bearing Surface	Counterbore	
		Max.	Min.	Max.	Min.					Diameter	Depth
	$B \times A$					C^3	D^4	E^5	F	H^6	G
4	$3\frac{1}{2} \times \frac{1}{2}$	$3\frac{17}{32}$	$3\frac{33}{64}$	$\frac{17}{32}$	$\frac{33}{64}$	$1\frac{7}{8}$	$\frac{1}{4}$	$\frac{3}{4}$	. .	$1\frac{1}{32}$	$\frac{3}{16}$
	$3\frac{1}{2} \times \frac{3}{4}$	$3\frac{17}{32}$	$3\frac{33}{64}$	$\frac{25}{32}$	$\frac{49}{64}$	$1\frac{7}{8}$	$\frac{1}{4}$	$\frac{3}{4}$	. .	$1\frac{1}{32}$	$\frac{3}{16}$
	$3\frac{1}{2} \times 1$	$3\frac{17}{32}$	$3\frac{33}{64}$	$1\frac{1}{32}$	$1\frac{1}{64}$	$1\frac{7}{8}$	$\frac{1}{4}$	$\frac{3}{4}$	. .	$1\frac{1}{32}$	$\frac{7}{16}$
	$3\frac{1}{2} \times 1\frac{1}{2}$	$3\frac{17}{32}$	$3\frac{33}{64}$	$1\frac{17}{32}$	$1\frac{33}{64}$	$1\frac{7}{8}$	$\frac{1}{4}$	$\frac{3}{4}$	$\frac{5}{16}$	$1\frac{1}{32}$	$\frac{1}{4}$
	$3\frac{1}{2} \times 2$	$3\frac{17}{32}$	$3\frac{33}{64}$	$2\frac{1}{32}$	$2\frac{1}{64}$	$1\frac{7}{8}$	$\frac{1}{4}$	$\frac{3}{4}$	$\frac{5}{16}$	$1\frac{1}{32}$	$\frac{3}{4}$
	$3\frac{1}{2} \times 2\frac{1}{2}$	$3\frac{17}{32}$	$3\frac{33}{64}$	$2\frac{17}{32}$	$2\frac{33}{64}$	$1\frac{7}{8}$	$\frac{1}{4}$	$\frac{3}{4}$	$\frac{5}{16}$	$1\frac{1}{32}$	$1\frac{1}{4}$

TABLE 15.—DIMENSIONS FOR FINISHED BLANKS FOR CIRCULAR FORMING TOOLS WITH COUNTERBORED MOUNTING HOLE.—*Continued*

Group Number	Basic Blank Size[1]	Diameter B		Width A		Adjusting Holes[2]		Mounting Hole			
								Diameter	Bearing Surface	Counterbore	
										Diameter	Depth
	$B \times A$	Max.	Min.	Max.	Min.	C[3]	D[4]	E[5]	F	H[6]	G
5	$4 \times \frac{5}{8}$	$4\frac{1}{32}$	$4\frac{1}{64}$	$\frac{21}{32}$	$\frac{41}{64}$	$2\frac{1}{8}$	$\frac{5}{16}$	1	. .	$1\frac{11}{32}$	$\frac{1}{4}$
	4×1	$4\frac{1}{32}$	$4\frac{1}{64}$	$1\frac{1}{32}$	$1\frac{1}{64}$	$2\frac{1}{8}$	$\frac{5}{16}$	1	. .	$1\frac{11}{32}$	$\frac{1}{4}$
	$4 \times 1\frac{1}{2}$	$4\frac{1}{32}$	$4\frac{1}{64}$	$1\frac{17}{32}$	$1\frac{33}{64}$	$2\frac{1}{8}$	$\frac{5}{16}$	1	. .	$1\frac{11}{32}$	$\frac{3}{4}$
	4×2	$4\frac{1}{32}$	$4\frac{1}{64}$	$2\frac{1}{32}$	$2\frac{1}{64}$	$2\frac{1}{8}$	$\frac{5}{16}$	1	$\frac{7}{16}$	$1\frac{11}{32}$	$\frac{1}{4}$
	$4 \times 2\frac{1}{2}$	$4\frac{1}{32}$	$4\frac{1}{64}$	$2\frac{17}{32}$	$2\frac{33}{64}$	$2\frac{1}{8}$	$\frac{5}{16}$	1	$\frac{7}{16}$	$1\frac{11}{32}$	$\frac{3}{4}$
	4×3	$4\frac{1}{32}$	$4\frac{1}{64}$	$3\frac{1}{32}$	$3\frac{1}{64}$	$2\frac{1}{8}$	$\frac{5}{16}$	1	$\frac{7}{16}$	$1\frac{11}{32}$	$1\frac{1}{4}$
6	$5 \times \frac{5}{8}$	$5\frac{1}{32}$	$5\frac{1}{64}$	$\frac{21}{32}$	$\frac{41}{64}$	$2\frac{1}{8}$	$\frac{5}{16}$	1	. .	$1\frac{11}{32}$	$\frac{1}{4}$
	5×1	$5\frac{1}{32}$	$5\frac{1}{64}$	$1\frac{1}{32}$	$1\frac{1}{64}$	$2\frac{1}{8}$	$\frac{5}{16}$	1	. .	$1\frac{11}{32}$	$\frac{1}{4}$
	$5 \times 1\frac{1}{2}$	$5\frac{1}{32}$	$5\frac{1}{64}$	$1\frac{17}{32}$	$1\frac{33}{64}$	$2\frac{1}{8}$	$\frac{5}{16}$	1	. .	$1\frac{11}{32}$	$\frac{3}{4}$
	5×2	$5\frac{1}{32}$	$5\frac{1}{64}$	$2\frac{1}{32}$	$2\frac{1}{64}$	$2\frac{1}{8}$	$\frac{5}{16}$	1	$\frac{7}{16}$	$1\frac{11}{32}$	$\frac{1}{4}$
	5×3	$5\frac{1}{32}$	$5\frac{1}{64}$	$3\frac{1}{32}$	$3\frac{1}{64}$	$2\frac{1}{8}$	$\frac{5}{16}$	1	$\frac{7}{16}$	$1\frac{11}{32}$	$1\frac{1}{4}$
	5×4	$5\frac{1}{32}$	$5\frac{1}{64}$	$4\frac{1}{32}$	$4\frac{1}{64}$	$2\frac{1}{8}$	$\frac{5}{16}$	1	$\frac{7}{16}$	$1\frac{11}{32}$	$2\frac{1}{4}$

[1] Blanks are designated by the basic outside diameter and width. Blanks made of high-speed steel shall be stamped B.S.

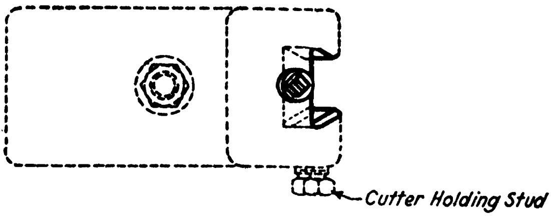
[2] Six adjusting holes shall have a minimum depth of $\frac{1}{4}$ inch greater depth or through holes optional. Adjusting holes shall be equally spaced on the C diameter circle and slightly chamfered.

[3] Diameter C of location circle shall be ± 0.002.

[4] Diameter of adjusting holes D shall be ± 0.002.

[5] Bolt hole E shall have a tolerance of $+0.003$, -0.000 with 45-degree chamfer at both ends.

[6] Diameter H shall have a slight radius at the bottom of counterbore.



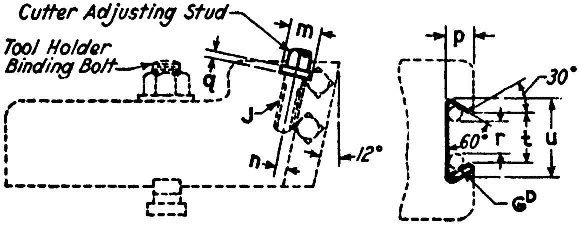


TABLE 16.—TYPICAL DOVETAILED FORMING TOOL HOLDER WITH COLLAR HEAD SCREW ADJUSTMENT
(Dimensions in Inches)

Machine Group Number	Dovetail					Screw Location	Adjusting Screw		
	Bottom Width[1]	Thickness	Between Plugs[2]	Plug Diameter	Top Width		Collar		Thread Size[4]
							Diameter	Thickness[3]	
	u	p	r	G^D	t	n	m	q	J
1	0.647	17/64	0.135	3/16	13/32	11/64	9/16	0.122	1/4–28
2	0.897	25/64	0.214	1/4	29/64	13/64	5/8	0.122	5/16–24
3	1.272	33/64	0.418	5/16	3/4	15/64	11/16	0.152	5/16–24
4	1.790	21/32	0 766	3/8	1 11/64	17/64	13/16	0.184	3/8–24
5	1.790	21/32	0.766	3/8	1 11/64	17/64	13/16	0 184	3/8–24
6	2.040	25/32	0.674	1/2	1 9/32	21/64	1	0.245	7/16–20

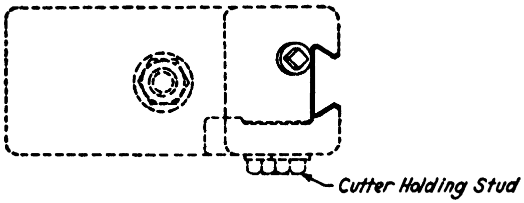
Tolerances for dimensions not otherwise specified shall be held to +0.010.

[1] Tolerance for the depth of dovetail p is ±0.003.

[2] Tolerance for the dovetail measured between plugs r is +0.002, −0.000.

[3] Tolerance for thickness of collar is +0.000, −0.002.

[4] The threads shall be made to Class 2 (NC-2, ASA B1.1–1935).



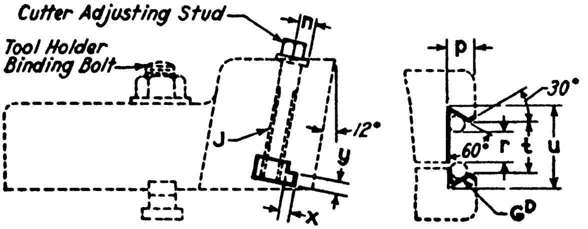


TABLE 17.—TYPICAL DOVETAILED FORMING TOOL HOLDER WITH HOOK BOLT ADJUSTMENT
(Dimensions in Inches)

Machine Group Number	Dovetail					Screw Location	Adjusting Stud and Nut		
	Bottom Width	Thickness[1]	Between Plugs[2]	Plug Diameter	Top Width		Length of Toe	Thickness of Toe	Thread Size[3]
	u	*p*	*r*	G^D	*t*	*n*	*x*	*y*	*J*
1	0.647	17/64	0.135	3/16	13/32	7/32	1/8	1/8	1/4–28
2	0.897	25/64	0.214	1/4	29/64	1/4	3/16	3/16	5/16–24
3	1.272	33/64	0.418	5/16	3/4	1/4	1/4	1/4	5/16–24
4	1.790	21/32	0.766	3/8	1 11/64	9/32	1/4	1/4	3/8–24
5	1.790	21/32	0.766	3/8	1 11/64	9/32	5/16	5/16	3/8–24
6	2.040	21/32	0.674	1/2	1 9/32	5/16	5/16	5/16	7/16–20

Tolerances for dimensions not otherwise specified shall be held to +0.010.

[1] Tolerance for the depth of dovetail *p* is ±0.003.

[2] Tolerance for the dovetail measured between plugs *r* is +0.002, −0.000.

[3] The threads shall be made to Class 2 (NC 2, ASA B1.1–1935).

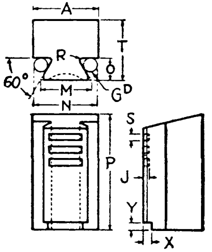


TABLE 18.—DIMENSIONS FOR FINISHED BLANKS FOR DOVETAILED FORMING TOOLS
(Dimensions in Inches)

Group Number	Basic Blank Size[1]	Width *A*		Thickness *T*		Length	Dovetail			Across Plugs	Plug Diameter	Adjusting Slot		Notch for Adj. Nut[5]	
		Max.	Min.	Max.	Min.		Width	Height	Radius			Width	Depth	Width	Depth
						P	*M*[2]	*O*	*R*	*N*[3]	*G*	*S*[4]	*J*	*Y*	*X*
1	1	1 1/32	1 1/64	1 1/32	1 1/64	1 1/8	5/8	1/4	1/32	0.849	3/16	1/8	1/8	1/8	1/8
	1 1/4	1 9/32	1 17/64	1 1/32	1 1/64	1 1/8	5/8	1/4	1/32	0.849	3/16	1/8	1/8	1/8	1/8
2	1 1/4	1 9/32	1 17/64	1 13/32	1 25/64	1 1/2	7/8	3/8	1/32	1.125	1/4	1/8	1/8	3/16	3/16
	1 1/2	1 17/32	1 33/64	1 13/32	1 25/64	1 1/2	7/8	3/8	1/32	1.125	1/4	1/8	1/8	3/16	3/16
	1 3/4	1 25/32	1 49/64	1 13/32	1 25/64	1 1/2	7/8	3/8	1/32	1.125	1/4	1/8	1/8	3/16	3/16

TABLE 18.—DIMENSIONS FOR FINISHED BLANKS FOR DOVETAILED FORMING TOOLS.—*Continued*

Group Number	Basic Blank Size[1]	Width A		Thickness T		Length	Dovetail			Across Plugs	Plug Diameter	Adjusting Slot		Notch for Adj. Nut[5]	
		Max.	Min.	Max.	Min.	P	Width M[2]	Height O	Radius R	N[3]	G	Width S[4]	Depth J	Width Y	Depth X
3	$1\frac{3}{4}$	$1\frac{25}{32}$	$1\frac{49}{64}$	$1\frac{29}{32}$	$1\frac{57}{64}$	2	$1\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{32}$	1.526	$\frac{5}{16}$	$\frac{5}{32}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{4}$
	2	$2\frac{1}{32}$	$2\frac{1}{64}$	$1\frac{29}{32}$	$1\frac{57}{64}$	2	$1\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{32}$	1.526	$\frac{5}{16}$	$\frac{5}{32}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{4}$
	$2\frac{1}{4}$	$2\frac{9}{32}$	$2\frac{17}{64}$	$1\frac{29}{32}$	$1\frac{57}{64}$	2	$1\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{32}$	1.526	$\frac{5}{16}$	$\frac{5}{32}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{4}$
	$2\frac{3}{4}$	$2\frac{25}{32}$	$2\frac{49}{64}$	$1\frac{29}{32}$	$1\frac{57}{64}$	2	$1\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{32}$	1.526	$\frac{5}{16}$	$\frac{5}{32}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{4}$
4	$2\frac{3}{4}$	$2\frac{25}{32}$	$2\frac{49}{64}$	$2\frac{17}{32}$	$2\frac{33}{64}$	$2\frac{1}{2}$	$1\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{16}$	2.053	$\frac{3}{8}$	$\frac{3}{16}$	$\frac{5}{32}$	$\frac{1}{4}$	$\frac{1}{4}$
	3	$3\frac{1}{32}$	$3\frac{1}{64}$	$2\frac{17}{32}$	$2\frac{33}{64}$	$2\frac{1}{2}$	$1\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{16}$	2.053	$\frac{3}{8}$	$\frac{3}{16}$	$\frac{5}{32}$	$\frac{1}{4}$	$\frac{1}{4}$
	$3\frac{1}{2}$	$3\frac{17}{32}$	$3\frac{33}{64}$	$2\frac{17}{32}$	$2\frac{33}{64}$	$2\frac{1}{2}$	$1\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{16}$	2.053	$\frac{3}{8}$	$\frac{3}{16}$	$\frac{5}{32}$	$\frac{1}{4}$	$\frac{1}{4}$
	4	$4\frac{1}{32}$	$4\frac{1}{64}$	$2\frac{17}{32}$	$2\frac{33}{64}$	$2\frac{1}{2}$	$1\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{16}$	2.053	$\frac{3}{8}$	$\frac{3}{16}$	$\frac{5}{32}$	$\frac{1}{4}$	$\frac{1}{4}$
5	$2\frac{3}{4}$	$2\frac{25}{32}$	$2\frac{49}{64}$	$3\frac{1}{32}$	$3\frac{1}{64}$	3	$1\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{16}$	2.053	$\frac{3}{8}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{5}{16}$	$\frac{5}{16}$
	3	$3\frac{1}{32}$	$3\frac{1}{64}$	$3\frac{1}{32}$	$3\frac{1}{64}$	3	$1\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{16}$	2.053	$\frac{3}{8}$	$\frac{3}{16}$	$\frac{5}{32}$	$\frac{5}{16}$	$\frac{5}{16}$
	$3\frac{1}{2}$	$3\frac{17}{32}$	$2\frac{33}{64}$	$3\frac{1}{32}$	$3\frac{1}{64}$	3	$1\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{16}$	2.053	$\frac{3}{8}$	$\frac{3}{16}$	$\frac{5}{32}$	$\frac{5}{16}$	$\frac{5}{16}$
	4	$4\frac{1}{32}$	$4\frac{1}{64}$	$3\frac{1}{32}$	$3\frac{1}{64}$	3	$1\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{16}$	2.053	$\frac{3}{8}$	$\frac{3}{16}$	$\frac{5}{32}$	$\frac{5}{16}$	$\frac{5}{16}$
6	3	$3\frac{1}{32}$	$3\frac{1}{64}$	$3\frac{17}{32}$	$3\frac{33}{64}$	4	2	$\frac{3}{4}$	$\frac{1}{16}$	2.500	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{3}{16}$	$\frac{5}{16}$	$\frac{5}{16}$
	$3\frac{1}{2}$	$3\frac{17}{32}$	$3\frac{33}{64}$	$3\frac{17}{32}$	$3\frac{33}{64}$	4	2	$\frac{3}{4}$	$\frac{1}{16}$	2.500	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{3}{16}$	$\frac{5}{16}$	$\frac{5}{16}$
	4	$4\frac{1}{32}$	$4\frac{1}{64}$	$3\frac{17}{32}$	$3\frac{33}{64}$	4	2	$\frac{3}{4}$	$\frac{1}{16}$	2.500	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{3}{16}$	$\frac{5}{16}$	$\frac{5}{16}$
	$4\frac{1}{2}$	$4\frac{17}{32}$	$4\frac{33}{64}$	$3\frac{17}{32}$	$3\frac{33}{64}$	4	2	$\frac{3}{4}$	$\frac{1}{16}$	2.500	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{3}{16}$	$\frac{5}{16}$	$\frac{5}{16}$

[1] Blanks are designated by the group number and the basic width; example. No. 1, 1 inch wide. Blanks made of high-speed steel shall be stamped H.S.

[2] Dovetail width M is to the theoretical sharp corners.

[3] The tolerance for width of dovetail N measured across plugs G is $+0.003$ or -0.003.

[4] Tolerance for width of adjusting slot S is $+0.003$, -0.000.

[5] The hook bolt and notched dovetail tool is an optional method of adjustment.

Carbide Tools

There are so many factors involved in the economical use of recent discoveries in high cutting speeds that many become confused and feel that nothing can be done without new machine equipment. While many machines now in use have neither power, speed, nor rigidity sufficient to utilize carbide cutters to their maximum capacity, production can be improved in most cases by a careful study of the various conditions necessary to secure greater output.

As tool cost is a major consideration, both first cost and tool life are important. While the cost of carbides is much less than formerly and will probably be still further reduced, the use of fewer teeth lessens cutter cost as well as the cost of grinding.

For this reason the use of fewer tips lessens the cost both for carbide and for brazing them to the body. Experience indicates that tool life is increased by using thicker tips. Even with no saving in total carbide cost, there is still less expense in the attaching of the tips to the cutter bodies. Care must be taken to be sure that the brazing is well done, as heavy chip loads per tooth sometimes loosen the tips from the body.

Some find that the use of the induction coil gives better results than that of the torch, and that the body of the cutter should be heated hotter than the tip itself. Arthur A. Schwartz of Bell Aircraft Corporation finds that the brazing material known as Eutectic No. 1800 gives good results.

There is also a tendency to make cutters with teeth of solid carbide clamped or wedged into a suitable body of cast metal such as Mehanite or of low carbon steel.

Tool life and work finish are affected by the smoothness of the cutter surface. This depends both on the grade of abrasive used and on the relation between the wheel and the feed. A smooth chip surface on the tool permits an easier chip flow, takes less power, and reduces the heat of the chip. It is claimed that a 60-grit diamond wheel can be made to give a surface of ½ micro-inch if proper feed is used. Some prefer Norbide abrasive to diamond for this work. Finishing the chip surface with a hand lap is recommended by some, while others feel that if it is done by hand it cannot be uniform. In one case however unskilled workers were taught to lap tools satisfactorily.

There is also a process known as "vapor blast" by which a very fine abrasive is blown on the cutting surfaces to give an effect similar to that of honing. This is applied both to high-speed steel and to carbide cutters, with very uniform results.

SECTION XIII

PUNCH PRESS TOOLS

FINDING BLANKS FOR DRAWN AND FORMED WORK

The rules that follow will be found of value in aiding the diemaker to figure areas of circular segments, etc., and to determine the relation between circles and squares in regard to their areas. Various other plane figures are included in the table of rules, these being of forms that the diemaker has to calculate frequently. Rules are given also for finding areas of cone surfaces, spheres, and other figures.

Method of Finding the Diameters of Shell Blanks

This method for the finding of diameters of shell blanks applies also to other shapes which frequently occur in practice.

The method is based upon the surface of the shell in comparison with the area of the blank and should, therefore, be used only when light material is to be considered. In case of the flanged shapes the width of the flange should be small in proportion to the diameter.

CYLINDRICAL SHELL

Figure 1 shows a cylindrical shell of the diameter d and the depth h. To find the diameter of the blank, lay down the diameter d of the shell twice on a horizontal line, Fig. 2, add to this a distance equal to four times the depth h of the shell and describe a semicircle of which the total distance is the diameter. The vertical line D from the intersecting point with the circle to the horizontal line gives the desired blank diameter. Line D is to be drawn at a distance d from the end of the horizontal.

FLANGED SHELLS

If the shell has a flange as in Fig. 3, use the formula shown in Fig. 4.

In the case of a hemisphere, Fig. 5, lay down the diameter three times on the horizontal line and draw the vertical line at the distance d from the end, as in Fig. 6.

If the hemisphere has a flange as in Fig. 7, add a distance equal to twice the width of the flange to the horizontal line, as in Fig. 8. In any case, the length of the vertical line D gives the desired diameter of blank. The width of flange $= a$.

TAPER SHELLS

If a shell with tapering sides, Fig. 9, has to be drawn, multiply first the bottom diameter by itself and divide the product by the

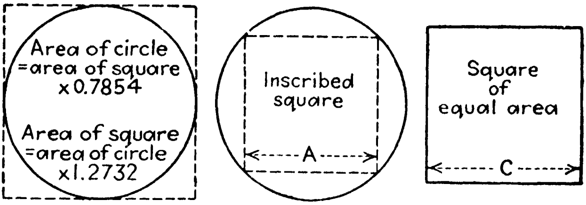

Area of circle =area of square x0.7854
Area of square =area of circle x1.2732
Inscribed square
A
Square of equal area
C

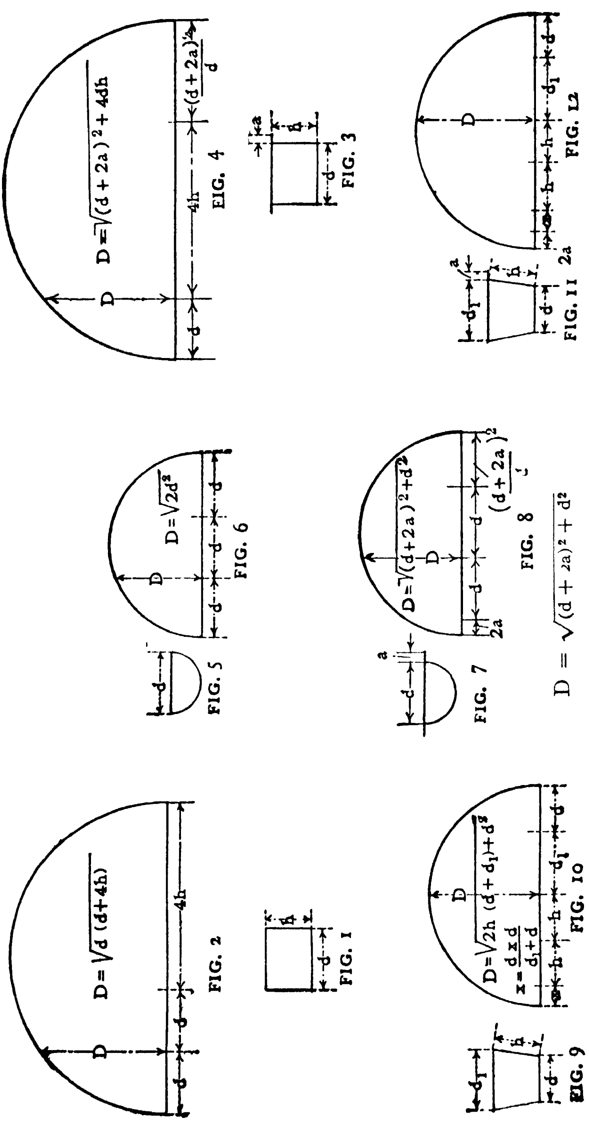
TABLE 1.—RULES FOR FINDING DIMENSIONS OF CIRCLES AND SQUARES

To Find	Having Given	Rule
Circumference....	Diameter	Multiply diameter by 3.1416 or divide diameter by 0.3183
Circumference.....	Area	Divide area by 0.07958 and find square root of quotient
Circumference.....	Side of an inscribed square *A*	Multiply side *A* by 4.443
Circumference.....	Side of square of equal area *C*	Multiply side *C* by 3.545
Diameter.........	Circumference	Multiply circumference by 0.3183 or divide circumference by 3.1416
Diameter..........	Area	Divide area by 0.7854 and find square root of quotient
Diameter..........	Side of an inscribed square *A*	Divide side *A* by 0.7071 or multiply side *A* by 1.4142
Diameter	Side of square of equal area *C*	Multiply side *C* by 1.1284 or divide side *C* by 0.8862
Radius............	Circumference	Multiply circumference by 0.15915 or divide circumference by 6.28318
Area..............	Circumference	Multiply the square of the circumference by 0.07958
Area	Diameter	Multiply the square of the diameter by 0.7854
Area	Radius	Multiply the square of the radius by 3.1416
Area....	Circumference and diameter	Multiply the circumference by one-quarter the diameter
Side of an inscribed square *A*	Diameter	Multiply diameter by 0.7071
Side of an inscribed square *A*	Circumference	Multiply circumference by 0.2251 or divide circumference by 4.4428
Side of a square of equal area *C*	Diameter	Multiply diameter by 0.8862 or divide diameter by 1.1284
Side of a square of equal area *C*	Circumference	Multiply circumference by 0.2821 or divide circumference by 3.545

sum of the two diameters d_1 and d in order to obtain the length x. Otherwise proceed as shown in Fig. 10.

FLANGED TAPER SHELLS

If the taper shell has a flange of the width a, Fig. 11, add to the base line of the diagram twice this width, as shown in Fig. 12.



$$D = \sqrt{(d + 2a)^2 + d^2}$$

FIGS. 1 to 12.—Finding the Diameters of Shell Blanks

TABLE OF DIAMETERS OF SHELL BLANKS

Table 3 shows the diameters of blanks for shells $\frac{1}{4} \times \frac{1}{4}$ inch to 6 × 6 inches inclusive, by $\frac{1}{4}$ inches. The figures were obtained by the formula that follows:

$$D = \sqrt{d(d + 4h)}$$

where d = diameter of finished shell.
h = height of finished shell.

They were also checked by figuring on the area of the metal.

If it is desired to punch the metal in one or more operations, get the mean height of the shell by the following formula:

$$m = \frac{h\,t}{T}$$

where m = mean height of finished shell.
h = height of finished shell.
t = thickness of finished shell.
T = thickness of metal before drawing.

Suppose, for example, a shell 2 inches in diameter by 6 inches high; thickness of metal before drawing, 0.040 inch; finish thickness of shell, 0.020 inch. Then

$$m = \frac{h\,t}{T} = \frac{6 \times 0.020}{0.040} = 3 \textit{ inches.}$$

By using this height from the table we find a shell 2 inches in diameter by 3 inches high requires a blank 5.29 inches diameter.

When the shell has rounded corners at the bottom, subtract the radius of the corner from the figures given in the table. Thus, in the last example, suppose the shell to have a radius of $\frac{1}{8}$ inch on the corner; 5.29 − 0.125 = 5.165 inches, the required diameter of the blanks.

FIG. 13.—Shells of Different Diameters

When a shell has a cross-section similar to the ones shown in Fig. 13, the required blank diameter may be calculated by the following formula:

$$d = 1.1284\sqrt{\frac{W}{w\,t}}$$

where d = diameter of blank in inches
W = weight of shell.
w = weight of one cubic inch of the metal.
t = thickness of shell.

AREAS OF VARIOUS FIGURES

Areas of cone and other surfaces are given in Fig. 14.

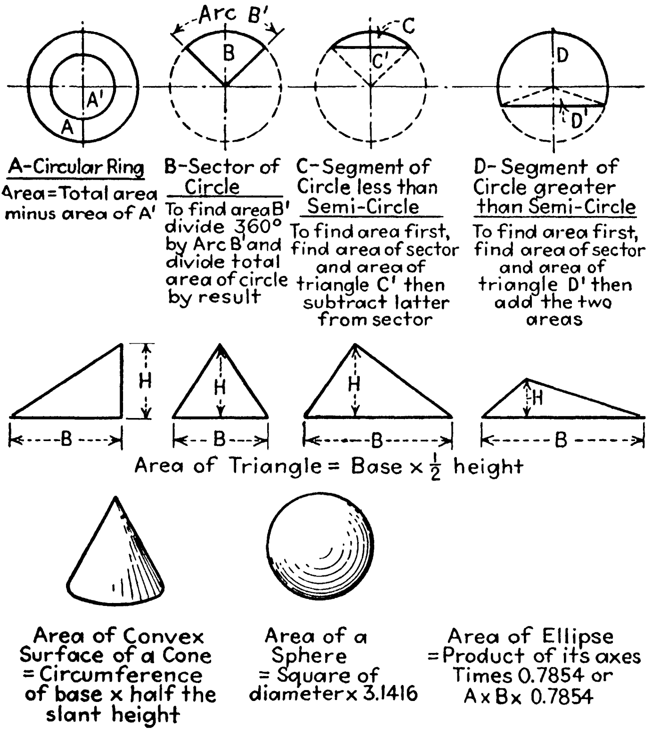

Arc B'
B
C
C'
D
D'
A'
A
A-Circular Ring
Area=Total area minus area of A'
B-Sector of Circle
To find area B' divide 360° by Arc B' and divide total area of circle by result
C-Segment of Circle less than Semi-Circle
To find area first, find area of sector and area of triangle C' then subtract latter from sector
D-Segment of Circle greater than Semi-Circle
To find area first, find area of sector and area of triangle D' then add the two areas
H
H
H
H
B
B
B
B
Area of Triangle = Base × ½ height
Area of Convex Surface of a Cone = Circumference of base × half the slant height
Area of a Sphere = Square of diameter × 3.1416
Area of Ellipse = Product of its axes Times 0.7854 or A × B × 0.7854

FIG. 14.—Areas of Various Figures

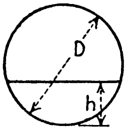
TABLE FOR AREAS OF SEGMENTS

It is often necessary to compute the areas of segments of circles for the purpose of finding either the amount of stock required for blanking such shapes in quantity or for figuring weights of material necessary for a certain press run of such parts. Occasionally there are other classes of work, besides sheet-metal jobs, where it is convenient to be able to find the areas of segments without resort to the customary roundabout process given in most formulas.

The accompanying table has been compiled to permit segments to be computed with little trouble, as the relative percentages of segment heights and areas of discs to the same radius are given in adjacent columns. Thus, if we divide the diameter of a circle by the height of a segment, we get the "Per Cent Diameter." Then in the next column is found the "Per Cent Area" that this amount represents. If the circle diameter *D* is, say, 4 inches and the segment *h* has a height of 1 inch, the percentage is ¼, or 25 per cent. In the column of "Per Cent Area" find opposite 25 the value 19.54 per cent. The disc area in any table of circular areas is found to be 12.566, and 19.54 per cent of this will give the area of segment as 2.455 square inches.

Interpolation may be required in some cases where the increments of 1 per cent are rather large, but ordinarily the areas are determined directly with sufficient accuracy.

TABLE 2.—AREAS OF SEGMENTS OF CIRCLES



Showing Relation between Percentages of Diameter and Percentages of Area; Diameter Percentages Taken in Even Advances of 1 Per Cent

Per Cent Diameter	Per Cent Area	Per Cent Diameter	Per Cent Area	Per Cent Diameter	Per Cent Area	Per Cent Diameter	Per Cent Area	Per Cent Diameter	Per Cent Area
1	0.170	21	15.28	41	38.60	61	63.90	81	86.77
2	0.477	22	16.30	42	39.88	62	65.14	82	87.76
3	0.873	23	17.37	43	41.11	63	66.37	83	88.74
4	1.337	24	18.45	44	42.37	64	67.59	84	89.68
5	1.869	25	19.54	45	43.64	65	68.82	85	90.60
6	2.443	26	20.66	46	44.90	66	70.03	86	91.50
7	3.077	27	21.78	47	46.17	67	71.24	87	92.36
8	3.746	28	22.91	48	47.44	68	72.43	88	93.20
9	4.457	29	24.05	49	48.72	69	73.60	89	94.02
10	5.203	30	25.23	50	50.	70	74.77	90	94.80
11	5.983	31	26.40	51	51.28	71	75.95	91	95.56
12	6.795	32	27.57	52	52.56	72	77.09	92	96.25
13	7.638	33	28.76	53	53.83	73	78.22	93	96.92
14	8.502	34	29.97	54	55.10	74	79.34	94	97.61
15	9.403	35	31.18	55	56.36	75	80.46	95	98.13
16	10.32	36	32.41	56	57.63	76	81.55	96	98.66
17	11.26	37	33.63	57	58.89	77	82.63	97	99.13
18	12.24	38	34.86	58	60.12	78	83.70	98	99.52
19	13.28	39	36.10	59	61.40	79	84.74	99	99.83
20	14.23	40	37.35	60	62.65	80	85.77	100	100.00

EXAMPLE.—A segment to be blanked is of height 0.50 inch, diameter of disc or circle is 2 inches. $\frac{0.5}{2} = 0.250$ or 25 per cent. In column under head "Per Cent Diameter," find 25 and opposite in next column, "Per Cent Area" find 19.54 per cent. That is, the segment ½ inch high of a 2-inch disc will have an area 19.54 per cent of the disc area, and the weight of segment will be 19.54 per cent of the total disc weight.

TABLE 3.—DIAMETER OF BLANKS FOR SHELLS, ¼ × ¼ INCH TO 6 × 6 INCHES

Shell Diameter	Height of Shell											
	¼"	½"	¾"	1"	1¼"	1½"	1¾"	2"	2¼"	2½"	2¾"	3"
				E								
¼"	0.56	0.75	0.90	1.03	1.14	1.25	1.35	1.44	1.52	1.60	1.68	1.75
½"	0.87	1.12	1.32	1.50	1.66	1.80	1.94	2.06	2.18	2.29	2.40	2.50
¾"	1.14	1.44	1.68	1.89	2.08	2.25	2.41	2.56	2.70	2.84	2.97	3.09
1"	1.41	1.73	2.00	2.24	2.45	2.65	2.83	3.00	3.16	3.32	3.46	3.61
1¼"	1.68	2.01	2.30	2.56	2.79	3.01	3.21	3.40	3.58	3.75	3.91	4.07
1½"	1.94	2.29	2.60	2.87	3.12	3.36	3.57	3.78	3.97	4.15	4.33	4.50
1¾"	2.19	2.56	2.88	3.17	3.44	3.68	3.91	4.13	4.34	4.53	4.72	4.91
2"	2.45	2.83	3.16	3.46	3.74	4.00	4.24	4.47	4.69	4.90	5.10	5.29
2¼"	2.70	3.09	3.41	3.75	4.04	4.31	4.56	4.80	5.03	5.25	5.46	5.66
2½"	2.96	3.36	3.71	4.03	4.33	4.61	4.87	5.12	5.36	5.59	5.81	6.02
2¾"	3.21	3.61	3.98	4.31	4.62	4.91	5.18	5.44	5.68	5.92	6.15	6.37
3"	3.46	3.87	4.24	4.58	4.90	5.20	5.48	5.74	6.00	6.25	6.48	6.71
3¼"	3.71	4.13	4.51	4.85	5.18	5.48	5.77	6.04	6.31	6.56	6.80	7.04
3½"	3.97	4.39	4.77	5.12	5.45	5.77	6.06	6.34	6.61	6.87	7.12	7.36
3¾"	4.22	4.64	5.03	5.39	5.73	6.05	6.35	6.64	6.91	7.18	7.44	7.69
4"	4.47	4.90	5.29	5.66	6.00	6.32	6.63	6.93	7.21	7.48	7.75	8.00
4¼"	4.72	5.15	5.55	5.92	6.27	6.60	6.91	7.22	7.50	7.78	8.05	8.31
4½"	4.98	5.41	5.81	6.19	6.54	6.87	7.19	7.50	7.79	8.08	8.35	8.62
4¾"	5.22	5.66	6.07	6.45	6.80	7.15	7.47	7.78	8.08	8.37	8.65	8.92
5"	5.48	5.92	6.32	6.71	7.07	7.42	7.75	8.06	8.37	8.66	8.94	9.22
5¼"	5.73	6.17	6.58	6.97	7.33	7.68	8.02	8.34	8.65	8.95	9.24	9.52
5½"	5.98	6.42	6.84	7.23	7.60	7.95	8.29	8.62	8.93	9.23	9.53	9.81
5¾"	6.23	6.68	7.09	7.49	7.86	8.22	8.56	8.89	9.21	9.52	9.81	10.10
6"	6.48	6.93	7.35	7.75	8.12	8.49	8.83	9.17	9.49	9.80	10.10	10.39

Shell Diameter	Height of Shell											
	3¼"	3½"	3¾"	4"	4¼"	4½"	4¾"	5"	5¼"	5½"	5¾"	6"
¼"	1.82	1.89	1.95	2.01	2.08	2.14	2.19	2.25	2.30	2.36	2.41	2.46
½"	2.60	2.69	2.78	2.87	2.96	3.04	3.12	3.21	3.29	3.36	3.44	3.50
¾"	3.21	3.33	3.44	3.54	3.65	3.75	3.85	3.95	4.04	4.13	4.22	4.31
1"	3.74	3.87	4.00	4.12	4.24	4.36	4.47	4.58	4.69	4.80	4.90	5.00
1¼"	4.22	4.37	4.51	4.64	4.77	4.91	5.03	5.15	5.27	5.39	5.50	5.62
1½"	4.66	4.82	4.98	5.12	5.27	5.41	5.55	5.68	5.81	5.94	6.06	6.18
1¾"	5.08	5.26	5.41	5.58	5.73	5.88	6.03	6.17	6.31	6.45	6.58	6.71
2"	5.48	5.66	5.83	6.00	6.16	6.32	6.48	6.63	6.78	6.93	7.07	7.21
2¼"	5.86	6.05	6.23	6.41	6.58	6.75	6.91	7.07	7.23	7.39	7.54	7.69
2½"	6.22	6.42	6.61	6.80	6.98	7.16	7.33	7.50	7.66	7.82	7.98	8.14
2¾"	6.58	6.79	6.99	7.18	7.37	7.55	7.73	7.91	8.08	8.25	8.41	8.58
3"	6.93	7.14	7.35	7.55	7.75	7.94	8.12	8.31	8.49	8.66	8.83	9.00
3¼"	7.27	7.49	7.70	7.91	8.11	8.31	8.50	8.69	8.88	9.06	9.24	9.41
3½"	7.60	7.83	8.05	8.26	8.47	8.67	8.87	9.07	9.26	9.45	9.63	9.81
3¾"	7.92	8.16	8.38	8.61	8.82	9.03	9.24	9.44	9.63	9.83	10.02	10.20
4"	8.25	8.49	8.72	8.94	9.17	9.38	9.59	9.80	10.00	10.20	10.39	10.58
4¼"	8.56	8.81	9.04	9.28	9.50	9.72	9.94	10.15	10.36	10.56	10.76	10.96
4½"	8.87	9.12	9.37	9.60	9.84	10.06	10.28	10.50	10.71	10.92	11.12	11.32
4¾"	9.18	9.44	9.69	9.93	10.16	10.40	10.62	10.84	11.06	11.27	11.48	11.69
5"	9.49	9.75	10.00	10.25	10.49	10.72	10.95	11.18	11.40	11.62	11.83	12.04
5¼"	9.79	10.05	10.31	10.56	10.81	11.05	11.28	11.51	11.74	11.96	12.18	12.39
5½"	10.08	10.36	10.62	10.87	11.12	11.37	11.61	11.84	12.07	12.30	12.52	12.74
5¾"	10.38	10.66	10.92	11.18	11.44	11.69	11.93	12.17	12.40	12.63	12.85	13.08
6"	10.68	10.95	11.23	11.49	11.75	12.00	12.25	12.49	12.73	12.96	13.19	13.42

AREA AND WEIGHT CHART FOR STEEL STAMPINGS[1]

The area or weight, or both, of stock for steel stampings can be obtained from Fig. 14*A* when the width of the strip, the gaging length, and the gage of the stock are known.

Example.—Take a strip, 2.25 inches wide; gaging jump of 3.125 inches, and gage of metal, No. 14, U.S.S.

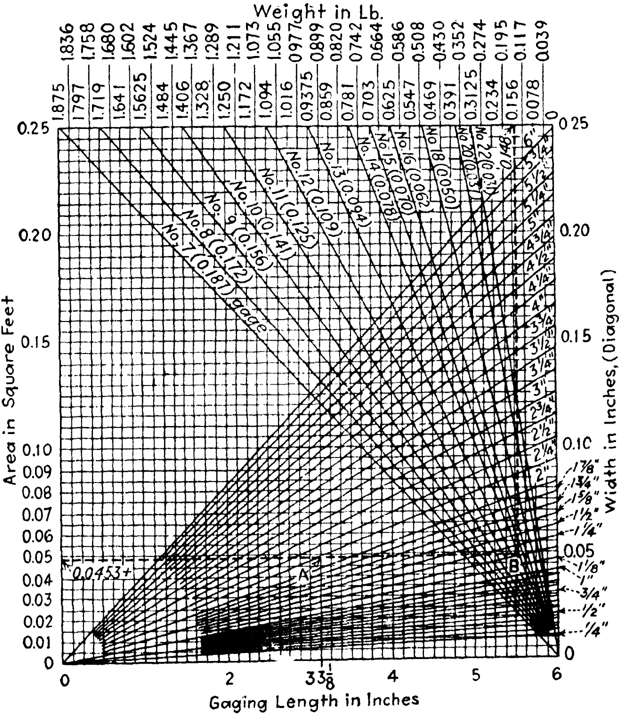


Fig. 14*A*.—Chart of Area and Weight

Start with a gaging length of 3⅛ inches at the foot of the chart and trace upward to the intersection with the diagonal representing 2¼ in. width of strip. Trace to the left to get the area of 0.0453 square foot.

To get the weight, trace right from *A* to *B* on the intersection with the 14-gage line. Trace upward to the top of the chart where the weight is read as 0.148 pound.

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[1] **Edward Heller.**

In either case the figure represents the area or the weight of one stamping. By moving the decimal point the information is obtained for 10, 100, or 1,000 stampings.

LAYING OUT BENDING DIES

National Cash Register Co. Method

For right-angle bends as in Fig. 15, where the radius of bend is less than $\frac{1}{64}$ inch, the custom is to multiply the thickness of stock by the constant 0.40 and add to the inside dimensions. Thus the length of blank L equals $A + B + 0.40t$. For bends having a radius greater than $\frac{1}{64}$ inch, and of any angle, the formula is $L = A + B + S\ (0.40t + R)$, where S is a constant for the angle taken from the accompanying table. The developed length of a blank can be computed by considering each bend separately.

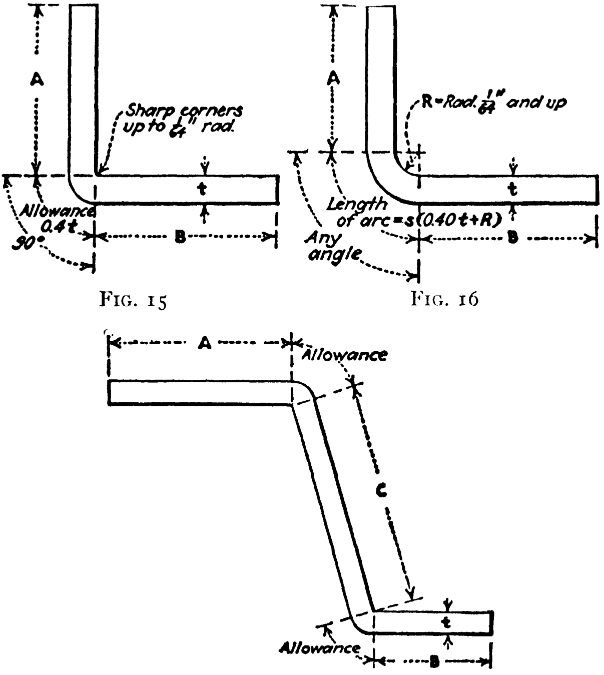


FIG. 15

FIG. 16

FIG. 17

FIGS. 15 to 17.—Right Angle and Other Bends

The formula for the length of blank in Fig. 17 is $L = A + B + C + 2S(0.40t + R)$; R = radius of bend.

For intricately formed blanks it has been found to be more satisfactory to cut out trial blanks for the forming dies.

For detailed tables of bends see pages 633-635.

TABLE 4.—CONSTANTS FOR ANGLE BENDS

Angle, Degree	Constant = S	Angle, Degree	Constant = S
0–10 minutes	0.0029	35	0.6109
0–30	0.0087	40	0.6981
1	0.0175	45	0.7854
2	0.0349	50	0.8728
3	0.0524	55	0.9599
4	0.0698	60	1.0472
5	0.0873	65	1.1345
10	0.1745	70	1.2217
15	0.2618	75	1.3090
20	0.3491	80	1.3963
25	0.4363	85	1.4835
30	0.5236	90	1.5708

PUNCH AND DIE CLEARANCE FOR ACCURATE WORK

In the blanking, perforating, and forming of flat stock in the power press for parts of adding machines, typewriters, etc., it is generally desired to make two different kinds of cuts with the dies used. First, to leave the outside of the blank of a semismooth finish, with sharp corners, free from burns, and with the least amount of rounding on the cutting side. Second, to leave the holes and slots that are perforated in the parts as smooth and straight as possible and true to size. The table given is the result of considerable experimenting on this class of work and has stood the test of years of use since it was compiled.

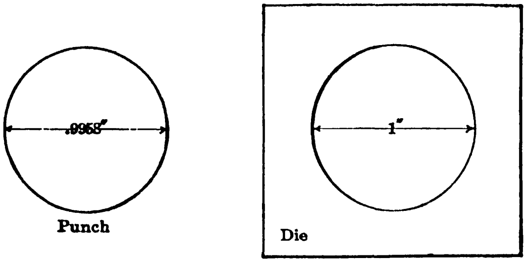


FIG. 18.—Blanking Tools

The die always governs the size of the work passing through it. The punch governs the size of the work that it passes through. In blanking work the die is made to the size of the work wanted and the punch smaller. In perforating work the punch is made to the size of the work wanted and the die larger than the punch. The clearance between the die and punch governs the results obtained.

Figures 18 and 19 show the application of the table in determining the clearance for blanking or perforating hard rolled steel 0.060 inch thick. The clearance given in the table for this thickness of metal is 0.0042, and Fig. 18 shows that for blanking to exactly 1-inch diameter, this amount is deducted from the diameter of the punch,

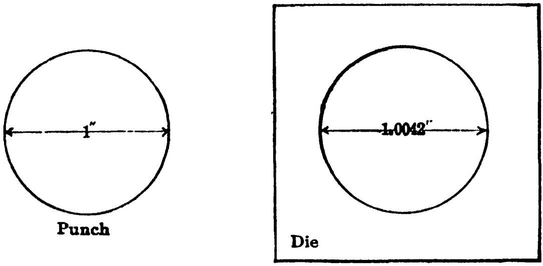


FIG. 19.—Perforating Tools

TABLE 5.—CLEARANCES FOR PUNCH AND DIE FOR DIFFERENT THICKNESS AND MATERIALS

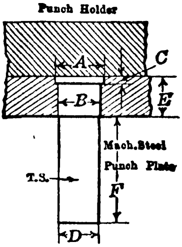
Thickness of Stock Inch	Clearance for Brass and Soft Steel Inch	Clearance for Medium Rolled Steel Inch	Clearance for Hard Rolled Steel Inch
.010	.0005	.0006	.0007
.020	.001	.0012	0014
.030	.0015	.0018	.0021
.040	.002	.0024	.0028
.050	.0025	.003	.0035
.060	.003	.0036	.0042
.070	.0035	.0042	.0049
.080	.004	.0048	.0056
.090	.0045	.0054	.0063
.100	.005	.006	.007
.110	.0055	.0066	.0077
.120	.006	.0072	.0084
.130	.0065	.0078	.0091
.140	.007	.0084	.0098
.150	.0075	.009	.0105
.160	.008	.0096	.0112
.170	.0085	.0102	.0119
.180	.009	.0108	.0126
.190	.0095	.0114	.0133
.200	.010	.012	.014

whereas for perforating the same amount is added, as in Fig. 19, to the diameter of the die. For a sliding fit make punch and die 0.00025 to 0.0005 inch larger; and for a driving fit make punch and die 0.0005 to 0.0015 inch smaller.

CLEARANCE FOR PUNCHES AND DIES FOR BOILER WORK

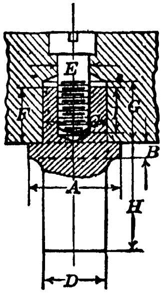
The practice of the Baldwin Locomotive Works on sizes up to 1¼ inches is to make the punch 1/64 inch below nominal size and the die 1/64 inch above size, which gives 1/32 inch clearance. Above 1¼ inches, the punches are made to nominal size and the dies 1/32 inch large, which allows the same clearance as before. The taper on dies below 1¼ inches is 1 inch in 12; on sizes above 1¼ inches, it is half this or ½ inch in 12 inches.

TABLE 6.—PIERCING PUNCHES



Diam. Punch D, Inches	A	B	C	E	F
0–1/4	5/16	.251	3/32	5/8	1 3/4
5/16	7/16	.3135	3/32	5/8	1 3/4
3/8	1/2	.376	3/32	5/8	1 3/4
7/16	9/16	.4385	3/32	5/8	1 3/4
1/2	5/8	.501	3/32	5/8	1 3/4
9/16	11/16	.5635	3/32	5/8	1 3/4
5/8	3/4	.626	3/32	5/8	1 3/4
11/16	13/16	.6885	3/32	5/8	1 3/4
3/4	7/8	.751	3/32	5/8	1 3/4

TABLE 7.—PIERCING PUNCHES HELD BY SET SCREWS



D = Diam. of Punch	A	B	C	E	F	G	H	I
1/4	5/8	1/8	1/2	5/16	1	1 1/8	1 1/8	5/8
3/8	5/8	1/8	1/2	5/16	1	1 1/8	1 1/8	5/8
1/2	3/4	1/8	1/2	5/16	1	1 1/8	1 1/8	5/8
9/16	3/4	1/8	5/8	3/8	1	1 1/8	1 1/8	5/8
5/8	7/8	1/8	5/8	3/8	1	1 1/8	1 1/8	5/8
3/4	7/8	1/8	5/8	3/8	1	1 1/8	1 1/8	5/8
7/8	1	1/8	3/4	3/8	1	1 1/8	1 1/8	5/8
1	1 1/8	1/8	3/4	3/8	1	1 1/8	1 1/8	5/8
1 1/8	1 1/4	1/8	3/4	3/8	1	1 1/8	1 1/8	5/8
1 1/4	1 3/8	5/32	1	3/8	1	1 1/8	1 1/8	5/8
1 1/2	1 5/8	5/32	1	3/8	1	1 1/8	1 1/8	5/8
1 3/4	1 7/8	5/32	1 1/4	3/8	1	1 1/8	1 1/8	5/8
2	2 5/16	5/32	1 3/8	3/8	1	1 1/8	1 1/8	5/8

Types of Punches

Table 6 covers a series of punches for various sizes of pierced holes. The punch bodies at a point immediately under the head are 0.001 inch large for fitting snugly in the punch plate as indicated. Such punches are readily ground to size and fitted to their places.

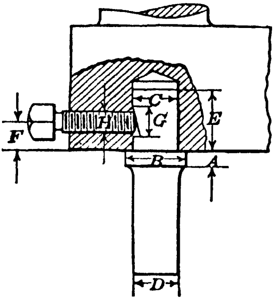
The punches in Table 7 are useful where they are close to the edge of the punch holder and therefore reached by setscrews. The sizes are given range from ¼ to 2 inches, and they are suited for blanking as well as piercing operations.

A substantial type of punch for either piercing or blanking is covered in various sizes by Table 8. This construction provides for the securing of the punch in its holder by means of a fillister head screw rapped in from the top as indicated.

PILOTS

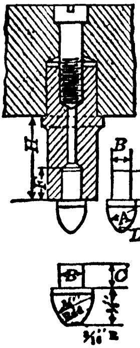
The pilot is inserted in the blanking punch and is made to a long radius, equal at least to the diameter of the pilot body. This

TABLE 8.—PUNCHES HELD BY SCREW TAPPED IN FROM THE TOP



D = Diam., Inches	*A*	*B*	*C*	*E*	*F*	*G*	*H*
¼	⅛	⅝	½	1	½	9/16	⅜
⅜	⅛	⅝	½	1	½	9/16	⅜
½	⅛	¾	½	1	½	9/16	⅜
9/16	⅛	¾	⅝	1¼	⅝	9/16	⅜
⅝	⅛	⅞	⅝	1¼	⅝	9/16	⅜
¾	⅛	⅞	⅝	1¼	⅝	9/16	⅜
⅞	⅛	1	¾	1½	¾	⅝	7/16
1	⅛	1	¾	1½	¾	⅝	7/16
1⅛	⅛	1⅛	¾	1½	¾	⅝	7/16
1¼	⅛	1¼	1	1¾	⅞	1 1/16	½
1½	⅛	1½	1	1¾	⅞	1 1/16	½
1¾	⅛	1¾	1¼	1⅞	⅞	1 3/16	⅝
2	⅛	2	1⅜	1⅞	⅞	1 3/16	⅝

TABLE 9.—PILOTS FOR PROGRESSIVE BLANKING PUNCHES

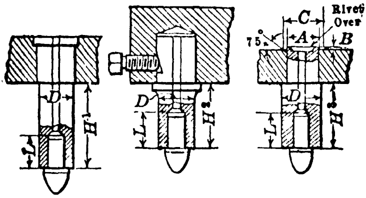


A, Inch	*B*	*C*	*D*	*E*	*F*	*H*
3/16	⅛	5/16	1/32	1/16	7/16	1 3/16
¼	3/16	7/16	1/32	1/16	9/16	1 3/16
5/16	¼	½	1/16	1/16	⅝	1 3/16
⅜	¼	½	1/16	1/16	⅝	1 3/16
7/16	¼	½	3/32	1/16	⅝	1 3/16
½	¼	½	⅛	1/16	⅝	1 3/16
⅝	5/16	9/16	5/32	1/16	11/16	1 3/16
11/16	5/16	9/16	Flat end	1/16	11/16	1 3/16
¾	⅜	⅝	Flat end	1/16	¾	1 3/16
⅞	⅜	⅝	Flat end	1/16	¾	1 3/16
1	7/16	11/16	Flat end	1/16	13/16	1 3/16
1 ¼	½	¾	Flat end	1/16	⅞	1 3/16

question of pilots is of interest as they are so extensively used in connection with progressive dies. Table 9 has been laid out to cover pilot dimensions for the type of punch which is held by a fillister head screw tapped in from the top of the punch holder. The same dimensions apply also to pilots for the other classes of punches whose proportions are given in Tables 6, 7, and 10, and in all cases the pilots should be ground or otherwise finished on the stem or shank to a press fit in the ends of the blanking punches.

Ordinarily the pilots can be made of drill rod. In the smaller sizes, as indicated in the tables, the point of the pilot is rounded to a definite radius given in Column *D*, Table 9. For larger sizes of

TABLE 10.—PROGRESSIVE BLANKING PUNCHES WITH PILOTS
For Pilot Dimensions Refer to Table 9
Make *L* for All Punches Equal to Pilot Shank + ⅛ Inch



D = Diam., Inches	*H*¹	*H*²	*H*³	*A*	*B*	*C*
¼	1 13/16	1 3/16				
5/16	1 13/16	1 3/16				
⅜	1 13/16	1 3/16				
7/16	1 13/16	1 3/16				
½	1 13/16	1 3/16				
9/16	1 13/16	1 3/16				
⅝	1 13/16	1 3/16	1 3/16	½	1/16	⅝
11/16	1 13/16	1 3/16	1 3/16	½	1/16	⅝
¾	1 13/16	1 3/16	1 3/16	½	1/16	⅝
⅞	.....	1 3/16	1 3/16	9/16	1/16	11/16
1	.....	1 3/16	1 3/16	⅝	1/16	¾
1 ⅛	.....	1 3/16	1 3/16	¾	1/16	⅞
1 ¼	.....	1 3/16	1 3/16	⅞	1/16	1
1 ½	.....	1 3/16	1 3/16	1⅛	3/32	1 5/16
1 ⅝	.....	1 3/16	1 3/16	1¼	3/32	1 7/16
1 ¾	.....	1 3/16	1 3/16	1 5/16	3/32	1 7/16
1 ⅞	.....	1 3/16	1 3/16	1 5/16	3/32	1 ½
2	.....	1 3/16	1 3/16	1⅜	3/32	1 9/16
2 ⅛	.....	....	1 3/16	1⅜	3/32	1 9/16
2 ⅜	.....	....	1 3/16	1½	3/32	1 11/16
2 ⅝	.....	....	1 3/16	1¾	3/32	1 15/16
2 ⅞	.....	....	1 3/16	2	3/32	2 3/16

pilots, the bottom end is flat, reducing the length accordingly, and the corners are rounded to a radius of 3/16 inch. These proportions are varied, where necessary, but for a wide range of work, they have proved satisfactory.

ALLOWANCES FOR SHAVING

As for any given material, or grade of stock, the condition of the contour of the blank will vary with the thickness of the metal,

TABLE 11.—AMOUNT TO ALLOW ON A SIDE FOR SHAVING CONTOUR WHERE ONLY ONE SHAVE IS TAKEN

Thickness of Blank, Inch	Soft Steel, Inch	Half-hard Steel, Inch	Hard Steel, Inch	German Silver, Inch	Brass, Inch	Thickness of Blank, Inch
3/64 (.0468)	.0025	.003	.004	.005	.005	3/64 (.0468)
1/16 (.0625)	.003	.004	.005	.006	.006	1/16 (.0625)
5/64 (.0782)	.0035	.005	.006–.007	.007	.007	5/64 (.0782)
3/32 (.0938)	.004	.006	.007–.008	.008	.008	3/32 (.0938)
7/64 (.1094)	.005	.007	.009–.011	.010	.010	7/64 (.1094)
1/8 (.125)	.007	.009	.012–.014	.014	.014	1/8 (.125)

TABLE 12.—AMOUNT TO ALLOW ON A SIDE FOR SHAVING CONTOUR WHERE A SECOND SHAVING OPERATION IS USED

Thickness of Blank, Inch	Allowance for First Shave		
	Soft Steel, Inch	Half-hard Steel, Inch	Hard Steel, Inch
3/64 (.0468)	.0025	.003	.004
1/16 (.0625)	.003	.004	.005
5/64 (.078)	.0035	.005	.006 –.007
3/32 (.0938)	.004	.006	.007 –.008
7/64 (.1094)	.005	.007	.009 –.011
1/8 (.125)	.007	.009	.012 –.014

Thickness of Blank, Inch	Allowance for Second Shave		
	Soft Steel Inch	Half-hard Steel, Inch	Hard Steel. Inch
3/64 (.0468)	.00125	.0015	.002
1/16 (.0625)	.0015	.002	.0025
5/64 (.78)	.00175	.0025	.003 –.0035
3/32 (.0938)	.002	.003	.0035–.004
7/64 (1094)	.0025	.0035	.0045–.0055
1/8 (.125)	.0035	.0045	.006 –.007

the amount left for shaving should likewise vary and with a fair degree of uniformity from the thinner gages to the thick material. Similarly the allowance for any given thickness should vary for soft, half-hard, and hard material. In order to cover these allowances for steel blanks of the three grades noted, Table 11 has been developed and has been given thorough tests in connection with numerous shaving dies operating on different classes of work.

This table covers thicknesses of metal from $\frac{3}{64}$ inch to $\frac{1}{8}$ inch inclusive and also includes allowances for German silver and brass. For the latter two materials, it will be noted, the shaving allowances are double those for steel of the same thickness. Table 12 is arranged to give allowances where two shaving cuts are taken. From the quantities under the heading "Allowances for second shave," it will be seen that the amount left for the second shaving operation is one-half that for the first. Thus in the case of a soft steel blank $\frac{1}{16}$ inch thick requiring two shaving cuts, 0.003 inch would be allowed on a side for the first shaving die to remove and 0.0015 inch for the second shaving operation, or a total of 0.0045 inch on a side or 0.009 inch over all, the blanking dies being made 0.009 inch larger than the finished size of the piece.

THE EFFECT OF SHEARED TOOLS

Where the tools are sheared, that is, beveled off from one side to the other to give a gradual sloping cutting action, the pressure required is much less than given in the table, and may usually be taken at one-half of the pressures for flat tools for stock not over, say, $\frac{1}{4}$ inch thick. Beyond that a safer amount would be two-thirds of the pressure necessary for dies without shear.

TABLE OF DIE CLEARANCES OR RELIEF

It is of value to know how much increase in blanking die size occurs as the face is ground down in resharpening. Table 13 has been worked out to cover various angles of taper besides the conventional slope of $\frac{1}{2}$ degree on a side. Although the half-degree taper relief or clearance is almost universally used for ordinary dies, there are special instances where this angle has been exceeded, especially with certain piercing and perforating dies.

Whereas, ordinarily, the angle of $\frac{1}{2}$ degree on a side will allow of the free discharge of the slugs from perforated blanks, such materials as aluminum and similarly soft metals sometimes produce slugs that, in the small sizes particularly, tend to swage into the walls of the piercing die when forced down by the punch and because of the expanding action upon their limited areas. These slugs may then stick and stack up and, becoming welded together, are likely to cause the punch to break or the die to become chipped around the edges of the small hole.

The table is arranged to show the additional amount at each side of a die for every ten thousandths ground off of its top face.

This is much more than the average amount removed in one grinding, but it is a convenient increment to work from, and the quantities in the columns that follow are very readily modified to correspond to any special amount taken off the die face in the grinding operation.

Consider the half-degree column: The increase at each side of the die is entirely negligible when the first 0.010 inch has been ground from the face, and only after the die has been ground down 0.120 inch, or almost $\frac{1}{8}$ inch, does the diameter of the die become 0.001 inch greater on each side or 0.002 inch more over all.

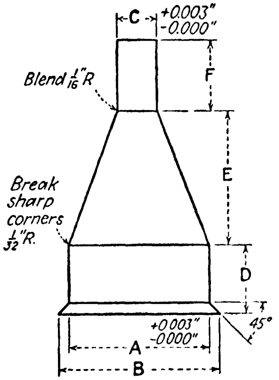
Another Table of Clearances between Punch and Die

Table 14 has been computed to cover clearances for all gages of material in the three gage standards commonly used for sheet metal.

This table has been worked out more in detail to give clearances based upon various percentages of stock thickness ranging from 5 to 12 per cent. The first column is arranged to advance by increments of 0.005 inch and directly opposite, under the respective gage headings, are grouped the actual gage equivalents most closely corresponding to the thickness in the first column.

Of the six columns of clearances, the first three are particularly adapted to very accurate work and small parts especially, 5 per cent being the allowance computed for brass and soft steel, 6 per cent for medium rolled steel, and 7 per cent for hard rolled steel. Similarly, the other three columns cover the general run of work where a little more clearance is permissible, 8 per cent being here allowed for brass and soft steel; 10 per cent for medium rolled steel; and 12 per cent for hard rolled steel.

These clearances apply to piercing dies as well as to dies for blanking.



A	B	C	D	E	F
0.437"	1/2"	0.099"	3/16"	1/16"	9/32"
0.437"	1/2"	0.125"	3/16"	1/16"	9/32"
0.437"	1/2"	0.187"	3/16"	1/16"	9/32"
0.437"	1/2"	0.250"	3/16"	1/16"	9/32"
0.437"	1/2"	0.316"	3/16"	1/16"	9/32"
0.437"	1/2"	0.193"	3/16"	1/16"	9/32"
0.250"	5/16"	0.099"	3/16"	1/16"	9/32"
0.250"	5/16"	0.128"	3/16"	1/16"	9/32"
0.250"	5/16"	0.193"	3/16"	1/16"	9/32"
0.250"	5/16"	0.161"	3/16"	1/16"	9/32"
0.250"	5/16"	0.136"	3/16"	1/16"	9/32"
0.250"	5/16"	0.209"	3/16"	1/16"	9/32"
0.250"	5/16"	0.099"	1/4"	1/8"	9/32"
0.250"	5/16"	0.099"	1/4"	1/4"	9/32"
0.250"	5/16"	0.193"	3/16"	1/16"	9/32"

Small Insert Punches at Bell Aircraft Corporation Are Made in Large Numbers to This Drawing and Table of Dimensions. Some Large Dies Have as Many as 750 Such Punches. In General, the Holes They Produce for Rivets Are Subsequently Enlarged by a Drill Which also Passes through the Mating Part.

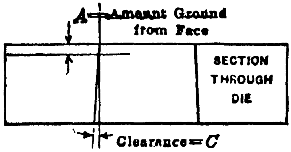


FIG. 19*a*.—Clearance Due to Grinding

TABLE 13.—DIE CLEARANCES OR RELIEF

A Amount Ground From Face of Die in Thousandths	*C* Clearance in Thousandths Corresponding to Degrees on Each Side				
Inch	½ Degree	1 Degree	1½ Degrees	2 Degrees	2½ Degrees
.010	.000087	.000175	.000262	.000349	.000437
.020	.000175	.000350	.000524	.000698	.000873
.030	.000241	.000525	.000786	.001047	.001310
.040	.000378	.000700	.001048	.001396	.001746
.050	.000437	.000875	.001310	.001745	.002183
.060	.000524	.001050	.001572	.002094	.002620
.070	.000611	.001225	.001834	.002443	.003016
.080	.000698	.001400	.002096	.003092	.003493
.090	.000776	.001575	.002358	.003141	.003929
.100	.000870	.001750	.002620	.003493	.004370
.110	.000960	.001925	.002882	.003839	.004803
.120	.001047	.002100	.003144	.004188	.005239
.130	.001135	.002275	.003406	.004537	.005677
.140	.001222	.002450	.003668	.004886	.006112
.150	.001309	.002625	.003930	.005235	.006549
.160	.001417	.002800	.004192	.005584	.006986
.170	.001484	.002975	.004554	.005933	.007422
.180	.001571	.003150	.004712	.006282	.007859
.190	.001658	.003325	.004978	.006631	.008295
.200	.001746	.003500	.005240	.006980	.008732
.210	.001827	.003675	.005502	.007329	.009169
.220	.001914	.003850	.005764	.007678	.009605
.230	.002001	.004025	.006026	.008027	.010042
.240	.002088	.004200	.006288	.008376	.010478
.250	.002175	.004375	.006550	.008725	.010915

TABLE 14.—CLEARANCE BETWEEN BLANKING PUNCH AND DIE

Thickness of Stock	Gage						Clearance Between Blanking Punch and Die Based Upon Percentage of Thickness					
	American or Brown & Sharpe		U. S. Standard for Plate		Birmingham or Stubbs							
	No.	Thickness	No.	Thickness	No.	Thickness	5 Per Cent.	6 Per Cent.	7 Per Cent.	8 Per Cent.	10 Per Cent.	12 Per Cent.
.005	40	.003144					.00025	.0003	.00035	.0004	.0005	.0006
	39	.003531										
	38	.003965										
	37	.004453										
	36	.005										
	35	.005614	38	.00625	36	.004						
	34	.006304	37	.006640	35	.005						
	33	.00708	36	.007031	34	.007						
.010	32	.00795	35	.007812	33	.008	.0005	.0006	.0007	.0008	.001	.0012
	31	.008928	34	.008593	32	.009						
	30	.010025	33	.009375	31	.010						
	29	.011257	32	.010156	30	.012						
			31	.010937								
.015	28	.012641	30	.0125	29	.013	.00075	.0009	.00105	.0012	.0015	.0018
	27	.014195	29	.014062	28	.014						
			28	.015625								
	26	.01594			27	.016						
.020	25	.0179	27	.017187	26	.018	.0010	.0012	.0014	.0016	.002	.0024
			26	.01875	25	.020						
	24	.0201	25	.021875	24	.022						

.025	23	.022571	24	.025	23	.025	.00125	.0015	.00175	.0020	.0025	.0030
	22	.025347	23	.028125	22	.028						
.030	21	.028462					.00150	.0018	.0021	.0024	.0030	.0036
	20	.031961	22	.03125	21	.032						
.035	19	.03589	21	.034375	20	.035	.00175	.0021	.00245	.0028	.0035	.0042
.040	18	.040303	20	.0375	19	.042	.002	.0024	.0028	.0032	.004	.0048
.045	17	.045257	19	.04375			.00225	.0027	.00315	.0036	.0045	.0054
.050	16	.05082	18	.050	18	.049	.0025	.0030	.0035	.0040	.0050	.0060
.055	15	.057068	17	.0562			.00275	.0033	.00385	.0044	.0055	.0066
.060					17	.058	.003	.0036	.0042	.0048	.006	.0072
.065	14	.064084	16	.0625	16	.065	.00325	.0039	.00455	.0052	.0065	.0078
.070	13	.071961	15	.070312	15	.072	.0035	.0042	.0049	.0056	.007	.0084
.075							.00375	.0045	.00525	.0060	.0075	.0090
.080	12	.080808	14	.078125			.004	.0048	.0056	.0064	.008	.0096
.085					14	.083	.00425	.0051	.00595	.0068	.0085	.0102
.090	11	.090742					.0045	.0054	.0063	.0072	.009	.0108
.095			13	.09375	13	.095	.00475	.0057	.00665	.0076	.0095	.0114
.100	10	.10189					.005	.0060	.007	.0080	.010	.0120
.105							.00525	.0063	.00735	.0084	.0105	.0126
.110			12	.109375	12	.109	.00550	.0066	00770	.0088	.011	.0132
.115	9	.11443					.00575	.0069	.00805	.0092	.0115	.0138
.120					11	.120	.006	.0072	.00840	.0096	.012	.0144
.125			11	.125			.00625	.0075	.00875	.0100	.0125	.0150
.130	8	.12849					.00650	.0078	.00910	.0104	.013	.0156
.135					10	.134	.00675	.0081	.00945	.0108	.0135	.0162
.140			10	.140625			.007	.0084	.00980	.0112	.014	.0168
.145	7	.14428					.00725	.0087	.01015	.0116	.0145	.0174
.150					9	.148	.0075	.009	.01050	.0120	.015	.0180
.155							.00775	.0093	.01085	.0124	.0155	.0186
.160	6	.16202	9	.15625			.008	.0096	.01120	.0128	.016	.0192
.165					8	.165	.00825	.0099	.01155	.0132	.0165	.0198
170			8	.171875			.00850	.0102	.01190	.0136	.017	.0204
.175							.00875	.0105	.01225	.0140	.0175	.0210
.180					7	.180	.009	.0108	.01260	.0144	.018	.0216

TABLE 14.— *Continued*

Thickness of Stock	Gage						Clearance Between Blanking Punch and Die Based Upon Percentage of Thickness					
	American or Brown & Sharpe		U. S. Standard for Plate		Birmingham or Stubbs							
	No.	Thickness	No.	Thickness	No.	Thickness	5 Per Cent.	6 Per Cent.	7 Per Cent.	8 Per Cent.	10 Per Cent.	12 Per Cent.
.185	5	.18194					.00925	.0111	.01295	.0148	.0185	.0222
.190			7	.1875			.00950	.0114	.01330	.0152	.019	.0228
.195							.00975	.0117	.01365	.0156	.0195	.0234
.200							.0100	.0120	.01400	.0160	.020	.0240
.205	4	.20431	6	.203125	6	.203	.01025	.0123	.01435	.0164	.0205	.0246
.210							.01050	0126	.01470	.0168	.021	.0252
.215							.01075	.0129	.01505	.0172	.0215	.0258
.220			5	.21875	5	.220	.0110	.0132	.01540	.0176	.022	.0264
.225							.01125	.0135	.01575	.0180	.0225	.0270
.230	3	.22942					.01150	.0138	.01610	.0184	.023	.0276
.235			4	.234375			.01175	.0141	.01645	.0188	.0235	.0282
.240					4	.238	.01200	.0144	.01680	.0192	.024	.0288
.245							.01225	.0147	.01715	.0196	.0245	.0294
.250	2	.25763	3	.250	3	.259	.01250	.0150	,01750	,0200	,025	.0300

TABLE 15.—DIE CLEARANCE FOR HOT FLANGING TOOLS

Plate Thickness, in Inches	Clearance, in Inches	Shrinkage, in Inches per Foot
0.75	0.100	0.125
0.625	0.083	0.125
0.50	0.067	0.125
0.375	0.050	0.125
0.25	0.033	0.125
0.1875	0.025	0.125
0.125	0.017	0.125
0.100	0.012	0.125
Figures below are for slightly heated plates worked on power presses		
0.1875	0.010	0.0625
0.128	0.006	0.0625
0.104	0.004	0.0625

DOUBLE-ACTION PRESS DIES

Double-action dies may be either "push-through" tools or they may be of "closed-bottom" type. The former design permits the drawn work to be pushed through and out of the dies upon the completion of the downstroke of the press. The closed form of die includes a push-out member, or knockout, which ejects the work

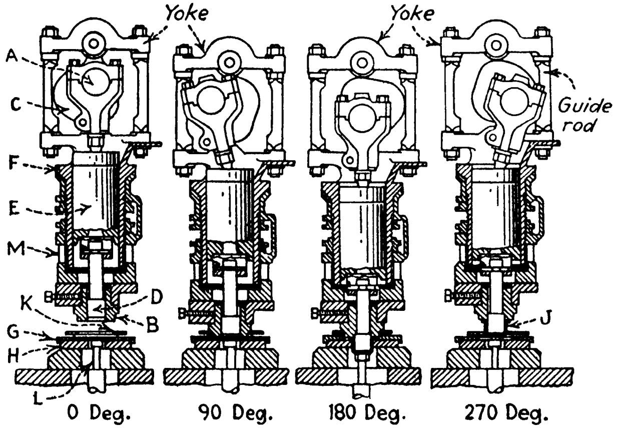


FIG. 20.—Typical Blanking and Drawing Dies

from the top of the die opening. Both types of dies are used in double-acting presses, and a typical position arrangement is shown in Fig. 20, which illustrates the double press gate as used by Waterbury-Farrel on its presses.

Figure 20 shows the arrangement of the tools and their operation in blanking and drawing a shell of typical proportions. Taking the left-hand section first, the crank *A* is seen in top position. Blanking punch *B* is actuated by the two cams *C* mounted on the crankshaft, and the drawing punch *D* is, of course, operated by the crank and plunger *E*. The drawing punch is secured by a key in the holder carried by the plunger *E*, and the plunger itself operates up and down through the sleeve *F* of the blanking gate-connecting mechanism.

In the 90-degree position shown in the group of sectional views, during the first 90-degree action of the crank, the blanking punch is brought down its full stroke, as shown. It cuts out the blank and forces it down through the blanking die *G* and holds it securely on top of the drawing die *H*. At the same time the drawing punch descends halfway, ready to draw the disc into shell form.

The second 90-degree movement of the crank (to the 180-degree position) holds the blank in position by means of the blanking punch while the drawing punch completes its downward stroke and draws the shell to depth.

During the third 90-degree crank movement (to 270 degrees) both punches rise together, and the blanking punch completes its upward stroke, but the drawing punch still has one-half of its upstroke remaining. Since the blanking punch remains stationary at this point while the drawing punch completes the last 90 degrees of action, the blanking punch serves as a stripper for the shell *J*.

Usually dies for blanking and drawing are equipped with a stripper *K* for the blanking punch. Where work is not drawn through the dies, a knockout, like *L*, is used under the dies. If the work is not ejected from the dies but is to be drawn through them, the action of the blanking gate *M* and the drawing plunger *E* is the same as described above, but the relative position of the tools is different, as the drawing punch must descend far enough into the dies so that the shell will be stripped from it by the underside of the drawing die itself. No knockout is required in the latter arrangement.

Typical Double-Acting Sub-Press

In Fig. 21 is shown a typical double-acting sub-press with a list of parts and the dimensions of each. The punch blanks and punches the piece at the same operation. A little study of the identification list on the right will make the operation clear. This is helped by showing the left side in the lower position.

TYPICAL STANDARD DIE SETS[1]

Classification Sheet for Class-A-A Die

Dies made under this heading shall be of the highest grade in workmanship and material, calculated to give maximum service for large production requirements, and shall have the following important features: leader pins and bushings hardened, ground, and lapped; automatic stop, first and second stop when necessary; die to be proper thickness best suited for the work, preferably not less than $\frac{7}{8}$ inch; cutting parts of the die to be within plus or minus 0.001-inch limits where required; the die to have $\frac{1}{4}$-degree taper for entire thickness or to be nearly straight for about $\frac{3}{8}$ to $\frac{1}{2}$ inch from top, followed by about 2-degree taper for balance of thickness; the die to have bushings for all small perforating holes whenever it is

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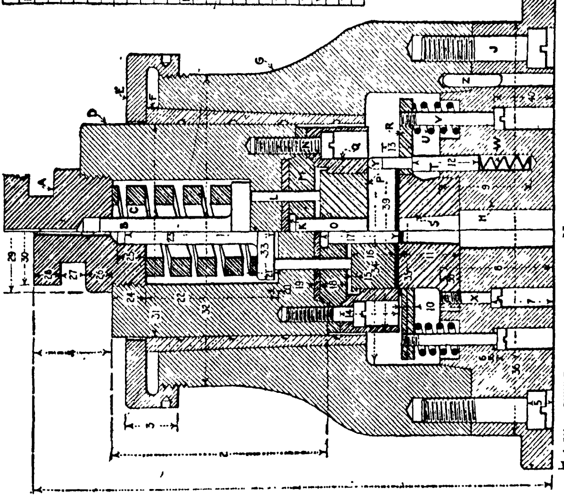
[1] Abstracted from specifications of National Die and Special Tool Builders Association.

Part Identification List

Pt	Name	Mat	Remarks
A	Cap adapter	T.S.	
B	Shedder plunger	T.S.	
C	Shedder spring	S.S.	Standard
D	Plunger	C.I.	carried
E	Frame cap	C.I.	in stock
F	Frame bushing	B.A.B.	assembled
G	Frame	C.I.	
H	Base	C.I.	Std Blank
J	Frame assembly Scr	M.S.	Standard
K	Support plate	T.S.	Std. Blank
L	Shedder push pin	T.S.	To suit
M	Punch plate	T.S.	Std Blank
N	Plunger assembly Scr	M.S.	Standard
O	Perforating punch	T.S.	To suit part
P	Shedder	T.S.	To suit part
Q	Die	T.S.	Std Blank
R	Stripper plate	T.S.	Std Blank
S	Punch	T.S.	To suit part
T	Starting pin	T.S.	Standard
U	Stripper spring	S.S.	"
V	Stripper screw	M.S.	"
W	Starting pin spring	S.S.	"
X	Punch assembly Scr	M.S.	"
Y	Stock guide pin	D.R.	"
Z	Dowel	D.R.	"

Left half shows punch down right side in raised position



	Main Dimensions		
No.	2	3	4
1	9 3/8"	10 1/4"	10 1/2"
2	5"	5 1/8	5 1/8
3	13/16"	1"	1 1/8"
4	1.324"	1.324"	1.324"
5	1/2"	1/2"	1/2"
6	To suit stock		
7	3/8"	1"	1"
8	1 3/8"	2"	2"
9	1 1/2"	1 7/8"	1 7/8"
10	7/32"	1/4"	1/4"
11	15/16"	1 1/8"	1 1/4"
12	3/4"	1 1/8"	1 1/4"
13	5/8"	5/8"	11/16"
14	13/16"	1"	1 1/8"
15	1/8"	1/8"	1/8"
16	To suit stock		
17	1 3/16"	1 3/8"	1 1/2"
18	1/2"	1/2"	1/2"
19	1/8"	1/8"	1/8"
20	To suit stock		
21	1/4"	5/16"	5/16"
22	3 1/2"	3 1/2"	3 1/2"
23	3 3/4"	3 3/4"	3 3/4"
24	5/8"	3/4"	3/4"
25	9/16"	11/16"	11/16"
26	7/16"	7/16"	7/16"
27	0.460"	0.460"	0.460"
28	0.427"	0.427"	0.427"
29	1 3/4"	2 3/8"	2 3/8"
30	1.615"	1.615"	1.615'
31	2.300"	3.250"	4.200"
32	3 1/2"	4 5/8"	6"
33	1 11/64"	1 59/64"	1 59/64"
34	3 1/16"	4 19/32"	5 1/4"
35	2 1/2"	4 1/4"	5"
36	5"	7"	8"
37	6"	8"	9"
38	3/8"	3/8"	3/8"
39	2 1/16"	3 3/32"	4 1/16"
40	15/16"	3/4"	1/8"

FIG. 21.—Part List and Main Dimensions Sub-Press Assembling Diagrams

possible to use bushings; the stripper plate to be machine steel, fitted closely to punch, and to have hardened steel bushings for all small perforators whenever possible; the punch to be solid with base; perforators, to be set in base of punch when possible; the perforators, if smaller than ¼ inch in diameter, shall be in hardened quills when possible; the punches and perforators to have spring shedder pins when possible; the punch to have, if possible, hardened steel backing plate to take the thrust of perforators, or hardened round discs of at least three times the diameter of perforators behind each perforator; dowel pins and holes to be ground and lapped; the clearance and line-up of cutting edges shall be such as to produce blanks smooth and free from burrs. These specifications are for extreme accuracy and large production requirements. These die sets are shown in Figs. 22 to 24.

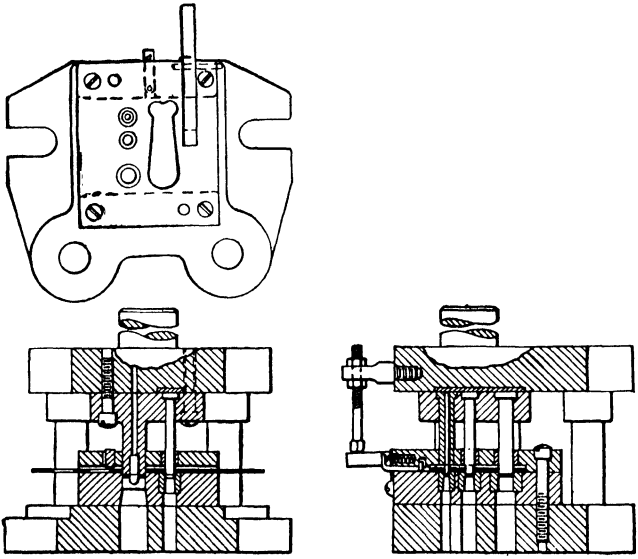


FIG. 22.—Section of Class A-A Die

Classification Sheet for Class-A Die

Dies made under this heading shall be of high-grade workmanship and material suitable for average requirements calculated to give long service for large production and shall have the following important features: leader pins and bushings to be hardened and ground; automatic stop, first and second stop when necessary; dies to be of proper thickness best suited for the work, preferably not less than ⅞ inch; cutting parts of the die to be within plus or

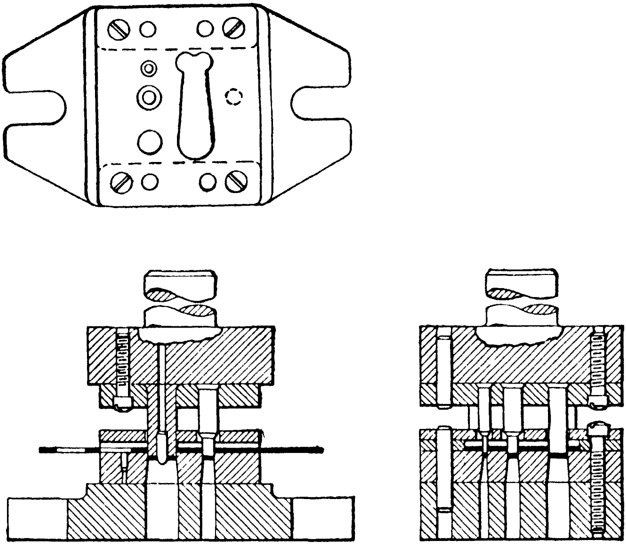


FIG. 23.—Section of Class-B Die

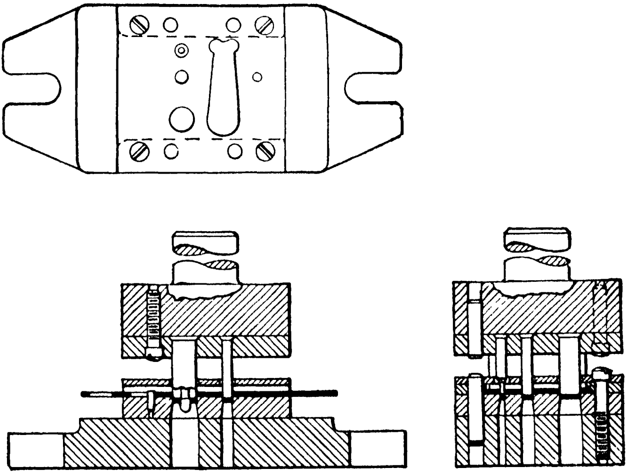


FIG. 24.—Section of Class-C Die

minus 0.002-inch limits where required; die to have ½-degree taper for entire thickness, and to have bushings for all small perforating holes whenever possible; stripper plate to be machine steel fitted to punch and perforator; punch to be solid with base or whenever possible set in machine steel plate; perforators to be set in punch base or whenever possible in plate; punches and perforators to have spring shedder pins for light material; small punches and perforators to have steel backing plate or discs behind each perforator; clearance between punch and die and line up of all cutting edges shall be such as to produce blanks free from burrs. These specifications are to be followed for the average first-class die for large production.

Classification Sheet for Class-B Die

Dies made under this heading shall be of first-class workmanship and material and shall have the following features: plain punch and die holders; plain flat or pin stop; die to be of proper thickness best suited for the work, preferably not less than $\frac{11}{16}$ inch; cutting parts of the die to be within plus or minus 0.003-inch limits; die to have ¾-degree taper for entire thickness; stripper plate to be machine steel and not contact with punch or perforator; punch to be set in machine steel plate or screwed to punch holder; perforator bushings to be set in die shoe casting whenever possible; clearance between punch and die to be such as to produce fairly smooth blanks, but small burrs are permissible. General appearance of the die is not important; refinements are not necessary. These specifications are to be followed for a die for medium production requirements or when dimensions are not important.

Classification Sheet for Class-C Die

Dies made under this heading shall be of first-class workmanship and material, but because of only small production requirements shall be known as temporary dies and shall have the following features: plain punch and die holders; plain flat or pin stop; die to be ½ inch or less in thickness, according to requirements; cutting parts to be within plus or minus 0.005-inch or more limits; die to have ¾- to 1-degree taper; stripper plate to be thin machine steel plate with strips underneath to form guide for stock and not to contact with punch or perforator; punch and perforators to be short and set in machine steel plate or held with screws.

STANDARDIZING NAMES OF DIE-SET PARTS

Technical Committee 9 of the American Society of Mechanical Engineers recommend that the present name of punch and die holders be changed to "die sets" as covering the subject more completely. It also recommends the following definitions for die set parts:

Die Sets.—The name given to the complete unit.
Punch Holder.—The name given to the upper member of a die set.
Die Holder.—The name given to the lower member of a die set.
Guide Post.—The portion of a set connecting the upper and lower units.
Guide Bushing.—The part into which the guide post functions.

Guide Holes.—The openings in either the punch or die holder into which the guide posts or guide bushings are placed.

Shank.—The projection portion of the punch holder which enters the hole in the ram of the press. Standard shanks may be of the inserted or integral types and either round or dovetail in shape.

Flange.—The portion of a die holder or punch holder to which the die holder or punch holder is bolted or clamped to the press.

STOCK STOPS FOR DIES

Some typical stops for dies are shown in Fig. 25. *A* is a plain stop, usually a piece of metal bent up at right angles, though oftentimes a pin or screw is let into the die as an end stop for the work. The angular stop has the advantage of ready adjustment by means of the screw that holds it in place. *B*, Fig. 25, is merely a side view of almost any form of trigger stop where the device is pivoted near the front (or sometimes back) of the die stripper and arranged to be struck by the trip pin on the downstroke of the press. The shape of the inner or working end of the stop trigger is modified to suit the size and shape of the blank opening into which it plays when released by the upstroke of the trip.

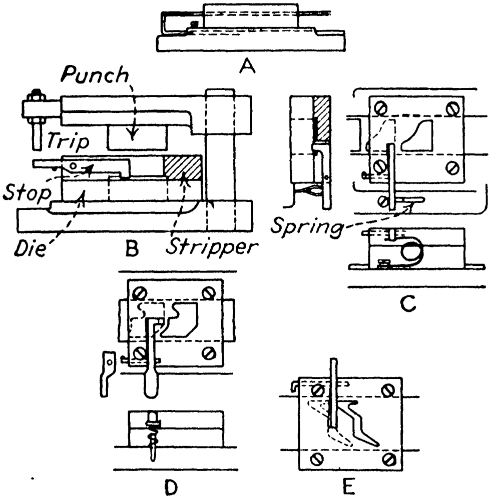


FIG. 25.—Stock Stops for Dies

The trigger stop may be placed, as shown by *C*, Fig. 25, in convenient position along the face of the stripper to contact with its bent end in a blanked opening in the work. Sometimes it is desirable to use an offset contact end like *D*, Fig. 25, particularly where it is preferred to stop against the central portion of the stock along an irregular contour, as shown in this sketch.

The stop trigger may be set at the rear of the die instead of toward the front—this is indicated in *E*, Fig. 25—or it may be fitted in at an angle, as is sometimes desirable, where it will clear guide posts, screws, or other parts to advantage.

Two kinds of springs are shown under the outer ends of the stops. In either case the spring is set to crowd the outer end of the stop to the left (where work is fed from the right) and to swing its working end to the right.

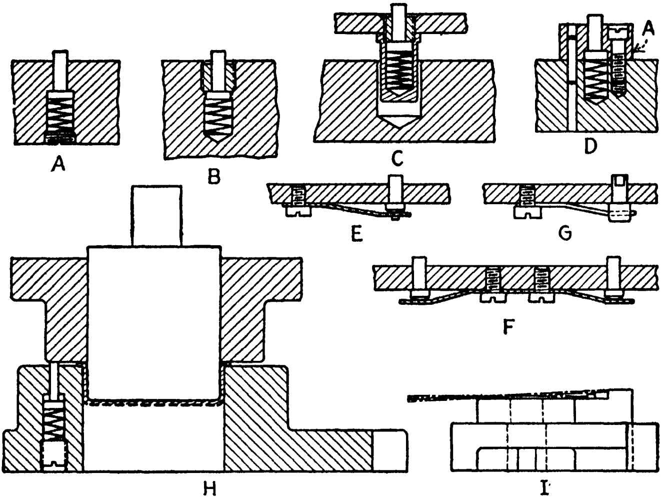


FIG. 26.—Disappearing Gage Pins. (*Contributed by Edward Heller*)

A—This type can be used where the shoe is heavy enough to house the spring and plug. The pin should be loose enough to slide freely, but not loose enough to collect dirt

B—Where the base is exceptionally thick, it is better to drill from the top

C—Same type as *B* hung to a movable stripper. The spring socket enters a clearance hole in the die shoe

D—Built-up in holder. Piece *A* is held by two screws and two dowel pins

E—Flat spring type. The pin end of the spring is slotted to prevent turning

F—Where two pins are used and the spring is held by two screws, it is not necessary to slot the ends of the spring

G—The up and down movement of a pin tends to rotate it slowly. Drilling the head for a wire prevents this. This type may be flattened on the side or sides, if necessary

H—Application to a shell drawing die in a double acting press. Two pins are used to gage the blank, and are depressed by the blank holder

I—In some cases it is desired to punch holes at different distances from the edge in the same die. The disappearing gage pin permits this

The trigger fits freely in the slot in the stripper plate, and slight tapered side clearance is provided in the inner end of the slot.

COMPOUND-DIE CONSTRUCTION

In simplest form the compound die produces at a single stage a pierced and blanked article, a simple washer form, say, like the piece over Fig. 27. The blanking die *A* is attached to the punch head by fillister head screws and dowels and is fitted with a shedder *C* which also fits the piercing punch *D* housed in the die shoe. Pressure pins *E*, acted upon by spring *F* in the shank keep the ejector flush with the face of blanking die *A*, except when forced up by the blanking operation when the punch head closes on the work on the downstroke of the press.

Blanking punch *G*, with flanged base in this case, has the piercing die hole in its center at *H* and has a close-fitting stripper-and-pressure-pad *I* held against four compression springs. When the upper die comes down on the stock, the blank is forced up against the action of shedder *C* and snapped out into the die, and at the same time the piercing punch knocks out the slug into die opening *H* which is tapered and cleared for free passage of slugs out of the dies.

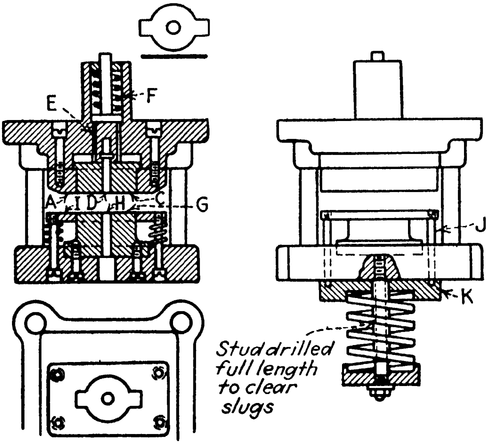


FIG. 27.—Compound-Die Construction

On the upstroke shedder *C* clears the blank out of die *A*. On some work of heavier gage the positive press knockout is used for shedding the blank from the upper die.

There are a number of ways of mounting stripper plate and springs and also different arrangements of shedder or ejector in die *A* depending on class of work, size, etc. Usually the pressure between stripper *I* and punch face *A* is sufficient to prevent wrinkling or buckling of the work.

At the right is a method of using a single heavy spring below the die shoe, the pins *J* extending down from the stripper to rest on the spring plate. Sometimes such a spring is a permanent attachment under the bolster of the press. In the die shown, the spring stud is drilled lengthwise to clear slugs as pierced from the work. When the strip of stock is pressed against the stop, the latter is pressed against its bearing surface at the left side in the stripper; but when its contact end is lifted from the stock by the descent of the punch holder the clearance at the inner end of the slot allows the side pressure of the spring at the front end of the stop to force the inner end of the stop to the right and cause it to drop onto the face of the strip of stock as the punch rises. Then the strip is readily fed along until the stop end again drops into a blanked opening.

HYDRO-PRESS FORMING

The development of airplane production, especially on the west coast, has included the use of rubber pressure pads to an extent not previously known. The following notes give this practice as a guide to those not familiar with the method.

Average rubber pressure of 1,000 to 1,500 pounds per square inch is satisfactory for thicknesses up to $\frac{3}{16}$ inch in 24SO. For

TABLE 15*a*.—TONNAGE CAPACITIES OF POWER PRESSES
Capacity of Crankshafts at the Bottom of the Stroke

Crank Shaft Diam., in Inches	Tons[1]		Crank Shaft Diam., in Inches	Tons[1]	
	Single Crank Press	Double Press Press		Single Crank Press	Double Crank Press
1$\frac{3}{8}$	6	.....	6$\frac{1}{2}$	150	150
1$\frac{1}{2}$	7.5	.....	7	180	180
1$\frac{5}{8}$	9	.....	7$\frac{1}{2}$	215	215
1$\frac{3}{4}$	10.5	.....	8	255	255
1$\frac{7}{8}$	12	.....	9	345	345
2	14	.....	10	440	450
2$\frac{1}{8}$	16	.....	11	545	650
2$\frac{1}{4}$	18	.....	12	665	900
2$\frac{1}{2}$	22	22	13	790	1,150
2$\frac{3}{4}$	26.5	26.5	14	920	1,400
3	31.5	31.5	15	1,060	1,700
3$\frac{1}{4}$	37	37	16	.....	2,000
3$\frac{1}{2}$	43	43	16$\frac{1}{2}$	1,300	
4	56	56	17	.....	2,300
4$\frac{1}{2}$	71	71	18	1,560	2,700
5	88	88	20	1,950	
5$\frac{1}{2}$	106	106	22	2,380	
6	126	126	24	2,860	

[1] The tonnage figures do not apply to end-wheel type of press with overhanging crankpin. (*Courtesy of Dayton Rogers Manufacturing Co.*)

heavier gages of 24ST the pressure must be from 2,000 to 3,000 pounds per square inch.

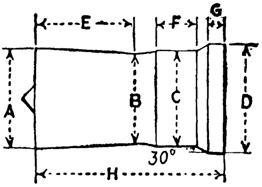
Minimum flange width to be formed is ⅛ inch for soft metal and $\frac{3}{16}$ inch for 24ST. This is in addition to the radius. One plant uses the following formulas, based on pressure of 1,000 to 1,200 pounds per square inch.

Minimum flange width 24SO = $\frac{1}{16}$ inch + 2.5 × thickness
Minimum flange width 24ST = ⅛ inch + 4 × thickness

It is customary practice to equip the average press with draw ring holding pressure one-sixth of the total press tonnage. In doing so, you are always assured of equipping your press with the *maximum* size cushion that will operate satisfactorily on a given press. On the average inclinable press, it is usually necessary to resort to tandem construction. To figure the draw ring holding pressure produced by a pneumatic die cushion, multiply the surface of the piston or pistons, in square inches, by the air pressure used on the given cushion, in square inches. Example: If an 8-inch size cushion is used, surface would be 48 square inches. If the working pressure from the shop air line to the cushion was 50 pounds per square inch, 50 times 48 equals 2,400 pounds, which would be developed on the draw ring. In other words, on a 50-pound maximum shop air line, using an 8-inch cushion, the approximate maximum draw ring holding pressure available would be 1⅕ tons.

U. S. NAVY PRACTICE

All punches and dies must be capable of punching 5,000 holes in medium steel plate, ⅛ inch less than the punch diameter, without regrinding. The proportions are shown in Tables 16 and 17.



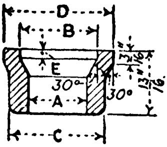


TABLE 16.—UNITED STATES NAVY STANDARD PUNCHES
(Dimensions in Inches)

Nominal Size	A	B		C	D	E	F	G	H
		Minimum	Maximum						
7/32	7/32	0.175	0.205	3/4	1	15/32	1	3/16	2 3/8
1/4	1/4	0.203	0.234	3/4	1	1/2	1	3/16	2 3/8
11/32	11/32	0.288	0.325	3/4	1	19/32	1	3/16	2 3/8
3/8	3/8	0.317	0.356	3/4	1	5/8	1	3/16	2 3/8
7/16	7/16	0.373	0.416	3/4	1	11/16	1	3/16	2 3/8
1/2	1/2	0.430	0.477	3/4	1	3/4	1	3/16	2 3/8
9/16	9/16	0.486	0.537	3/4	1	13/16	1	3/16	2 3/8
5/8	5/8	0.543	0.598	3/4	1	7/8	1	3/16	2 3/8
11/16	11/16	0.599	0.658	3/4	1	15/16	1	3/16	2 3/8
3/4	3/4	0.656	0.719	1 7/32	1 3/8	1	1/2	3/16	2 3/8
13/16	13/16	0.713	0.779	1 7/32	1 3/8	1 1/16	1/2	3/16	2 3/8
7/8	7/8	0.770	0.840	1 7/32	1 3/8	1 1/8	1/2	3/16	2 3/8
15/16	15/16	0.826	0.900	1 7/32	1 3/8	1 3/16	1/2	3/16	2 3/8
1	1	0.883	0.961	1 7/32	1 3/8	1 1/4	1/2	3/16	2 3/8
1 1/16	1 1/16	0.945	1.023	1 7/32	1 3/8	1 1/4	1/2	3/16	2 3/8
1 1/8	1 1/8	1.008	1.086	1 7/32	1 3/8	1 1/4	1/2	3/16	2 3/8
1 3/16	1 3/16	1.070	1.148	1 7/32	1 3/8	1 1/4	1/2	3/16	2 3/8
1 1/4	1 1/4	1.133	1.211	1 9/16	1 3/8	1 1/4	1/2	3/16	2 3/8
Tolerances (all sizes)	+0.005 −0.005	....	....	....	+0.005 −0.005	...	...	..	+0.000 −0.062

U. S. NAVY BUSHINGS FOR PUNCHES
(Dimensions in Inches)

	Dimensions	Tolerances	
		Plus	Minus
A	0.757	0.005	0.000
B	1.010	0.010	0.000
C	1.219	0.005	0.005
D	1.375	0.005	0.005
E	0.125	0.031	0.000

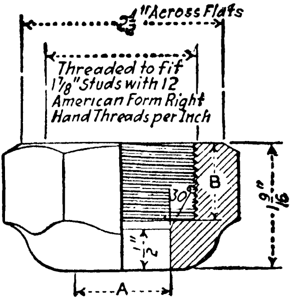

2 1/4" Across Flats
Threaded to fit 1 7/8" Studs with 12 American Form Right Hand Threads per Inch
B
30°
9/16"
1/2"
A

TABLE 17.—U. S. NAVY COUPLING NUTS FOR PUNCHES
(Dimensions in Inches)

Coupling Nut No.	A		B	
	Minimum	Maximum	Minimum	Maximum
1	1.230	1.240	0.875	1.000
2	1.570	1.580	0.875	1.000

NOTE.—No. 1 coupling nuts are for use in connection with punches up to and including $1\frac{3}{16}$ inches in diameter; No. 2 nuts are for punches $1\frac{1}{4}$ inches in diameter.

Pressure Required for Shearing or Punching

$$\frac{\text{Total length of cut in inches} \times \text{tensile strength of material in tons}}{\text{Thickness of metal in parts of inches}} = \text{pressure}$$

EXAMPLE.—Total length of cut = 20 inches. Tensile strength, 30 tons; thickness, $\frac{1}{4}$ inch; $20 \times 30 = 600 \div 4 = 150$ tons. Or tensile strength ÷ thickness × length of cut gives same result.

POWER REQUIRED FOR PUNCHING AND SHEARING

Experiments tend to show that, with steel plates of 60,000 pounds tensile strength, the metal is all sheared when the punch has passed one-half through the plate. The following formula by L. R. Pomeroy takes this into account and also allows the motor an efficiency of 80 per cent and the punching machine 75 per cent.

When T = full thickness of plate.
D = diameter of hole punched.
N = number of holes punched per minute.
P = horse-power required to drive machine.

$$P = \frac{T^2 \times D \times N}{3.78}.$$

Taking a ½-inch hole in a ½-inch plate, the power required to punch 30 per minute would be

$$\frac{\frac{1}{4} \times \frac{1}{2} \times 30}{3.78} = \frac{3.75}{3.78} \text{ or about 1 horse-power.}$$

Pressure required for shearing = length of cut × thickness in inches × shearing strength of material. Dies with "shear" reduce this one-third to one-half.

TABLE 17*a*.—TONS PRESSURE REQUIRED TO PUNCH MILD STEEL PLATE
Shearing Strength of 50,000 Pounds per Square Inch

Thickness of Metal		Hole Diameter, in Inches							
Gauge	Inches	⅛	¼	⅜	½	⅝	¾	⅞	1
20	0.036	0.35	0.71	1.1	1.4	1.8	2.1	2.5	2.8
18	0.048	0.47	0.94	1.4	1.9	2.4	2.8	3.3	3.8
16	0.060	0.59	1.2	1.8	2.4	2.9	3.5	4.1	4.7
14	0.075	0.74	1.5	2.2	2.9	3.7	4.4	5.2	5.9
12	0.105	1.0	2.1	3.1	4.1	5.2	6.2	7.2	8.3
11	0.120	1.2	2.4	3.5	4.7	5.9	7.1	8.3	9.4
10	0.135	....	2.7	4.0	5.3	6.6	8.0	9.3	10.6
3/16 in.	0.187	....	3.7	5.5	7.4	9.2	11.1	12.9	14.8
¼ in.	0.250	....	4.9	7.4	9.8	12.3	14.8	17.2	19.7
⅜ in.	0.375	....	....	11.1	14.8	18.5	22.1	25.8	29.5
½ in.	0.500	....	....	....	19.7	24.6	29.5	34.4	39.4
⅝ in.	0.625	....	....	....	....	30.8	36.9	43.0	49.2
¾ in.	0.750	....	....	....	....	....	44.3	51.7	59.0

To obtain the total pressure required for one-level punching, multiply the pressure shown in the chart by the number of holes to be punched. The resultant tonnage should not exceed approximately two thirds the rated capacity of the brake for smooth operation. If punches are stepped one-half of the metal thickness or more, the total pressure will be reduced as follows:

Punches on two levels, divide by 2.
Punches on three levels, divide by 3.
Punches on four levels, divide by 4.

A simple rule is: Multiply the length of the cut by the tensile strength of the material, in *tons*. This gives the pressure required to punch a 1-inch plate. Divide by the thickness of the plate in inches for pressure necessary, that is, if plate is ⅛ inch thick divide by 8; if 1/16 inch thick, divide by 16, etc.

STRENGTH OF PUNCH-PRESS SHAFT AND HOUSING

A similar rule for the strength of a crankshaft of not over 4-inch throw is: Square the diameter of the shaft and multiply by 3½.

By this rule, a 5-inch shaft with a throw not over 4 inches withstood a pressure of 5 × 5 × 3½ = 87½ tons.

In designing the housing, allow 1 square inch of area for each ton of pressure and make the housing 25 per cent stronger than the shaft.

These figures are for determining whether presses are strong enough for the work, rather than for designing.

APPROXIMATE PRESSURE IN POUNDS REQUIRED FOR PUNCHING AND SHEARING DIFFERENT THICKNESSES OF STEEL AND BRASS PLATE

TABLE 18.—PUNCHING PRESSURE

Number of Gauge U. S. Standard Plate	Figured for 1 Inch Diameter Hole Without Shear on Dies[1]		
	Steel, Pounds	High Carbon Steel	Brass, Pounds
20	5,890	8,835	4,123
18	7,854	11,781	5,498
16	9,817	14,726	6,872
13	14,765	22,148	10,335
11	19,635	29,452	13,744
$\frac{3}{16}$	29,452	44,178	20,616
$\frac{1}{4}$	39,270	58,905	27,489
$\frac{5}{16}$	49,087	73,631	34,361
$\frac{3}{8}$	58,905	88,357	41,233
$\frac{7}{16}$	68,722	103,080	48,104
$\frac{1}{2}$	78,540	117,810	54,978
$\frac{5}{8}$	98,175	147,262	68,722
$\frac{3}{4}$	117,810	176,715	82,467
$\frac{7}{8}$	137,445	206,167	96,211
1	157,080	235,620	109,956

---

[1] Other diameters in proportion.

TABLE 19.—APPROXIMATE PRESSURES IN POUNDS FOR PUNCHING BRASS AND STEEL; FOR 1-INCH DIAMETER OF HOLE

Gage, U. S. Standard Plate		Shearing Strength of Brass per Sq. In. = 35,000 Lb. Shearing Strength of Steel per Sq. In. = 50,000 Lb. Shearing Strength of High-carbon Steel per Sq. In. = 75,000 Lb.		
No.	Thickness	Brass	Steel	High-carbon Steel
28	.015625	1,718	2,454	3,681
27	.0171875	1,870	2,790	3,928
26	.01875	2,067	2,940	4,395
25	.021875	2,408	3,422	5,168
24	.025	2,749	3,927	5,890
23	.028125	3,080	4,396	6,640
22	.03125	3,440	4,914	7,316
21	.034875	3,781	5,385	8,024
20	.0375	4,123	5,890	8,835
19	.04375	4,816	6,876	10,484
18	.05	5,498	7,854	11,781
17	.05625	6,190	8,940	13,236
16	.0625	6,872	9,817	14,726
15	.0703125	7,696	10,990	16,520
14	.078125	8,597	12,246	18,408
13	.09375	10,335	14,765	22,148
12	.109375	11,985	17,110	25,721
11	.125	13,744	19,635	29,452
10	.140625	15,505	22,135	33,040
9	.15625	17,150	24,540	36,810
8	.171875	18,912	27,900	39,280
7	.1875	20,672	29,400	43,950
6	.203125	22,321	31,870	47,900
5	.21875	24,080	34,220	51,680
4	.234375	25,729	36,700	55,224
3	.250	27,490	39,270	58,900
2				
1				

RULE.—Multiply thickness of stock by length by shearing strength of material.

TABLE 20.—APPROXIMATE PRESSURE IN POUNDS FOR SHEARING BRASS AND STEEL FOR 1-INCH LENGTH OF CUT

Shearing strength of brass per sq. in. = 35,000 lb.
Shearing strength of steel per sq. in. = 50,000 lb.
Shearing strength of high-carbon steel per sq. in. = 75,000 lb.

Gage, U. S. Standard Plate		Pounds Pressure		
No.	Thickness	Brass	Steel	High-carbon Steel
28	.015625	546	780	1,170
27	.0171875	595	850	1,275
26	.01875	615	940	1,400
25	.021875	770	1,090	1,635
24	.025	875	1,250	1,875
23	.028125	980	1,405	2,100
22	.03125	1,085	1,560	2,340
21	.034375	1,190	1,715	2,550
20	.0375	1,312	1,875	2,812
19	.04375	1,540	2,185	3,280
18	.05	1,750	2,500	3,750
17	.05625	1,960	2,810	4,200
16	.0625	2,187	3,125	4,687
15	.0703125	2,480	3,515	5,250
14	.078125	2,710	3,905	5,850
13	.09375	3,290	4,700	7,050
12	.109375	3,815	5,465	8,200
11	.125	4,375	6,250	9,375
10	.140625	4,935	7,030	10,500
9	.15625	5,460	7,810	11,700
8	.171875	6,020	8,598	12,900
7	.1875	6,562	9,375	14,062
6	.203125	7,075	10,155	15,225
5	.21875	7,667	10,935	16,425
4	.234375	8,190	11,715	17,550
3	.250	8,750	12,500	18,750
2				
1				

RULE.—Multiply thickness of stock by length by shearing strength of material.

TABLE 21.—PENETRATION TABLE

(Table showing to what extent in shearing or punching operations soft steel has to be penetrated by the knives or punches to effect complete severance of the material.)

Thickness, inches	1	3/4	5/8	1/2	3/8	5/16
Percentage	0.25	0.31	0.34	0.37	0.44	0.47
Thickness, inches	1/4	3/16	1/8	3/32	1/16	1/32
Percentage	0.50	0.56	0.62	0.67	0.75	0.87

The percentage of other metals depends on their hardness.

TABLE 22.—SHEARING TABLE

Number of Gauge U. S. Standard Plate	Pressure Figured for 1 Inch Length without Shear on Dies		
	Steel, Pounds	High Carbon Steel	Brass, Pounds
20	1,875	2,812	1,312
18	2,500	3,750	1,750
16	3,125	4,687	2,187
13	4,700	7,050	3,290
11	6,250	9,375	4,375
3/16	9,375	14,062	6,562
1/4	12,500	18,750	8,750
5/16	15,625	23,437	10,937
3/8	18,750	28,125	13,125
7/16	21,875	32,812	15,312
1/2	25,000	37,500	17,500
5/8	31,250	46,875	21,875
3/4	37,500	56,250	26,250
7/8	43,750	65,625	30,625
1	50,000	75,000	35,000

Formula: Length × thickness × shearing strength of material = pounds of pressure required.

	POUNDS
Shearing strength per square inch of steel	50,000
Shearing strength per square inch of high carbon steel	75,000
Shearing strength per square inch of brass	35,000

Since most tools are sheared, the above pressure can be taken at one-half as given in table up to ¼-inch thickness in stock. Beyond ¼ inch, up to 1 inch, not less than two-thirds of the above given pressures should be taken for safe figuring on suitable press.

TABLE 23.—AVERAGE ULTIMATE STRENGTH OF MATERIALS
Pounds per Square Inch

Material	Shear	Compression	Tension
Aluminum, cast	12,000	12,000	15,000
Soft sheet	15,000	....	15,000
Half hard sheet	19,000	60,000	19,000
Hard sheet	25,000	....	28,000
Asbestos millboard	3,800		
Brass, cast	36,000	30,000	30,000
Drawing, soft sheet	30,000	....	47,000
Half hard sheet	35,000	....	60,000
Hard sheet	40,000	....	85,000
Bronze, gun metal	....	20,000	40,000
Phosphor, soft sheet	40,000	....	45,000
Manganese	....	120,000	70,000
Copper, cast	25,000	40,000	24,000
Rolled	28,000	60,000	37,000
Wire, annealed	....	....	36,000
Wire, unannealed	....	....	60,000
Dow-metal, cast	18,000	44,000	24,000
Duralumin, soft sheet	30,000	50,000	35,000
Treated	35,000	60,000	55,000
Treated and cold rolled	40,000	75,000	75,000
Fibre, hard	24,000		
German silver, half hard	32,000		
Iron, cast	25,000	90,000	22,000
Iron cast (2 per cent nickel)	50,000	150,000	50,000
Iron (25 per cent steel)	30,000	90,000	30,000
Iron, wrought	40,000	46,000	50,000
Iron wire, annealed	....	....	45,000
Iron wire, unannealed	....	....	80,000
Lead	4,000	....	3,000
Leather, chrome	7,000	....	10,000
Oak	7,000	....	4,000
Rawhide	13,000		
Monel metal, cast	60,000	....	75,000
Rolled	65,000	90,000	95,000
Nicro copper	30,000	....	37,000
Paper, hollow die	3,000		
Flat punch	8,500		
Bristol board, flat punch	4,800		
Strawboard, flat punch	3,500		
Silver	30,000		38,000
Steel, casting	60,000	65,000	70,000
Boiler plate	60,000	70,000	70,000
Cold drawn rod	58,000	....	65,000

TABLE 23.—AVERAGE ULTIMATE STRENGTH OF MATERIALS.—*Continued*
Pounds per Square Inch

Material	Shear	Compression	Tension
Drill rod, not tempered	80,000		130,000
Nickel (about 3½ per cent)	70,000		85,000
Plow			270,000
Silicon	65,000		65,000
Stainless	70,000		95,000
0.10 carbon (soft)	45,000	60,000	60,000
0.25 carbon (mild)	55,000	65,000	70,000
0.50 carbon	70,000		95,000
0.75 carbon	80,000		115,000
1.00 carbon	85,000		130,000
1.20 carbon tool steel annealed	95,000		150,000
1.20 carbon tool steel tempered	190,000		250,000
Wire, annealed			80,000
Wire, unannealed			120,000
Wire, crucible			180,000
Wire, suspension bridge			200,000
Wire, piano			300,000
Tin, cast		6,000	3,500
Sheet	5,000	6,500	5,000
Zinc, sand cast	14,000	20,000	9,000
Die cast	16,000		15,000
Rolled	18,000		24,000

In Fig. 28, page 627, is a diagram that makes it easy to estimate the pressure necessary to pierce different metals.

INFLUENCE OF STOCK WIDTH ON SCRAP

The waste of stock in punch-press work—always an important percentage of the original stock—will vary according to the location of the blank in relation to the edge of the strip of material and oftentimes also in respect to the number of blanks across the width of the metal.

The simplest form of blank, a circular piece, leaves considerable scrap when the strip of metal is wide enough for only one blank. An example is seen in Fig. 29, where a 1-inch blank is shown in three different widths of material, the waste scrap with the narrow strip amounts to more than 33 per cent of the total area in which the blank is enclosed. By doubling up, as shown, the scrap is reduced to something like 28 per cent, and, if still wider stock is used for three rows of blanks, the scrap is reduced still further or to about 22 per cent.

With irregular shapes, even with close nesting of the blanks in the strip, the waste is apt to be quite conspicuous. A typical case is that in Fig. 30 where two blanks are reversed end to end and interlocked as closely as feasible. In this instance the actual material in the blank is only one-half of the area used in producing these blanks. Fifty per cent of the stock comes out in scrap. The salvage value of brass absorbs some of the original cost of the metal represented by the scrap, though this seldom amounts to much more per pound than one-third of the price of the new material.

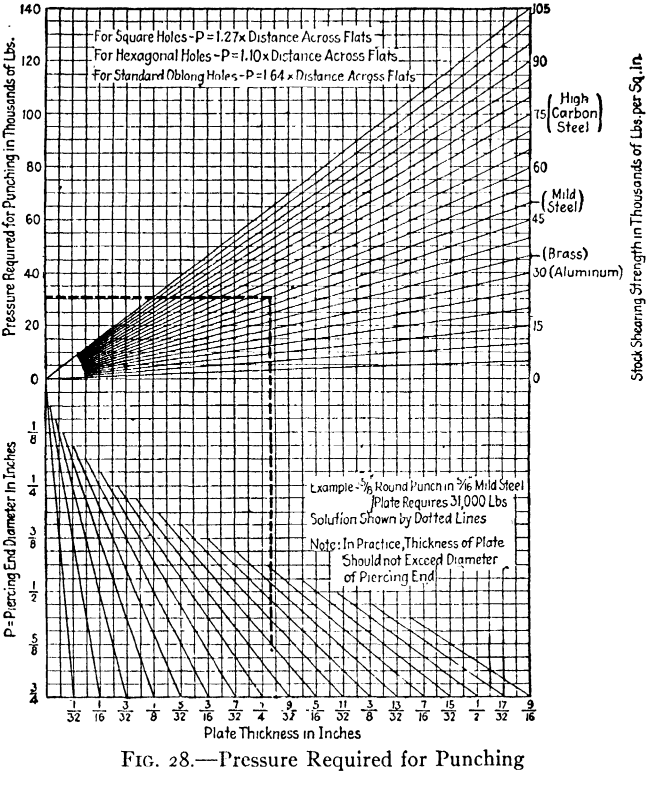


FIG. 28.—Pressure Required for Punching

RATE OF PRODUCTION

If blanks are medium length, they should be placed crosswise of the strip of stock or, if longer, should be at an angle, thus using narrower stock. Usually, the narrow blank permits of rapid hand feed. Usual runs in general specialty shops are hand fed.

Say the press flywheel runs at 120 to 125 revolutions per minute. On small work, the operation on simple blanking will keep up closely to regular speed of press. But time is lost in starting in a new length of stock, etc.

Tests of a number of special shapes indicate that an average of 60 to 65 blanks per minute is 3,000 to 4,000 blanks per hour.

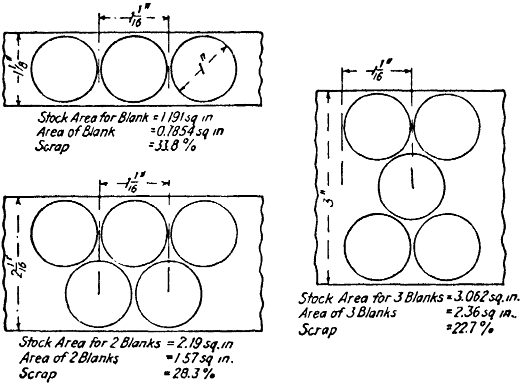

1 1/16"
1 1/8"
1"
Stock Area for Blank = 1 191 sq in
Area of Blank = 0.7854 sq in
Scrap = 33.8 %
1 1/16"
2 1/16"
Stock Area for 2 Blanks = 2.19 sq. in
Area of 2 Blanks = 1 57 sq in.
Scrap = 28.3 %
1 1/16"
3"
Stock Area for 3 Blanks = 3.062 sq. in.
Area of 3 Blanks = 2.36 sq in.
Scrap = 22.7 %

FIG. 29

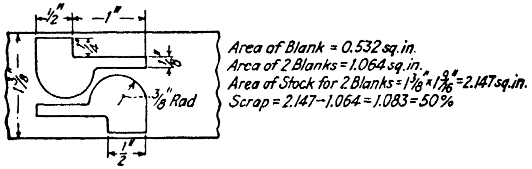

1/2"
1"
1/4
1/8
1 1/8
3/8" Rad
1/2"
Area of Blank = 0.532 sq. in.
Area of 2 Blanks = 1.064 sq. in.
Area of Stock for 2 Blanks = 1 3/8" × 1 9/16" = 2.147 sq. in.
Scrap = 2.147 − 1.064 = 1.083 = 50%

FIG. 30

FIGS. 29 and 30.—Locating Work on Strip Stock

This is a normal rate of production on small sample work with hand feed.

Second operations, with such as trimming, shaving, or some jobs of piercing, forming, and the like, are usually considerably slower than simple blanking for the reason that the pieces are hand-fed into a nest or other locating device, instead of being run from the strip of stock. A fair average on such work will range from 25 to 30 or 35 pieces per minute if close nesting is not necessary.

Some shops apply simple chutes or slides for guiding blanks into the dies for second-operation runs; this acts to increase speed somewhat and particularly to safeguard the process of feeding.

Where gang dies (multiple dies) are used for blanking two or more pieces at once, they speed up production proportionately.

Some shops do not recommend going to additional expense for such tools unless press runs are to exceed 200,000 or 250,000 blanks. The argument is that, for smaller lots than this, the extra cost of the tools is not justified. This is especially the case where the ultimate amount of work to be run is indefinite because of desirable changes in design or a fluctuation in the market for the product. Therefore, the design of the dies should be based upon the amount of work they are likely to be required to run before being discarded.

Second operations in drawing cups, formulas, etc., are necessarily slower than usual second runs as it takes longer to place and remove the cup. Cups 2 by 2½ inches, for example, can, on the average, be drawn up at 12 to 15 per minute depending on the method used in locating the blank and ejecting the drawn piece.

LUBRICANT FOR PRESS TOOLS

Although there are some shops where no lubricant is used when working sheet metal and where good results are obtained, still it is best to use a lubricant on all classes of sheet-metal work.

For all cutting of dies on brass and steel, a heavy animal oil is best. Pure lard oil is very satisfactory, although expensive.

When punching copper or German silver, a thin coating of lard oil or sperm oil should be spread over the sheets or strips before punching. A good way to do this evenly is to coat one sheet thickly and then feed it through a pair of rolls, after which a number of other sheets may be run through the rolls and thus coated evenly. For drawn work this method of coating the sheets from which the shells are to be drawn will be found to be the best, as the coating of oil on the stock will be very thin and it will not be found necessary to clean the shells afterward, the oil having disappeared during the blanking and drawing process. When oil is applied with a pad or brush, the coating will be so thick that it will be necessary to clean the article produced.

Lubricant for Drawing Steel Shells

In drawing steel shells, a mixture of equal parts of oil and black lead is very useful, and, although it may be used warm, it does not affect the work as much as the speed of the drawing press does; the thicker the stock, the slower must be the speed of the punch. A heavy grease with a small proportion of white lead mixed in with it is also recommended for this purpose.

If the drawing die is very smooth and hard at the corner of the "draw," or edge of the die, the liability of clogging will be reduced to a minimum. Often it will help to give to the die a lateral polish by taking a strip of emery cloth and changing the grain of the polish from circular to the same direction as the drawing.

Lubricants for Brass

For drawing brass or copper, a clean soap water is considered most satisfactory. One of the largest brass firms in this country uses a preparation made by putting 15 pounds of Fuller's soap in a barrel of hot water and boiling until all the lumps are dissolved. This is used as hot as possible. If the work is allowed to lie in the water until a slime has formed on the shell it will draw all the better. A soap that is strong in resin or potash will not give good results.

In drawing zinc, the water should be hot, or the percentage of broken shells will be large.

Aluminum is an easy metal to draw, but it hardens up very quickly. For lubricants, lard oil, melted Russian tallow, and vaseline are all good. The lubricant should be applied to both sides of the metal.

Lubrication for Hot Dies

The life of hot dies, for either hot pressing or die casting, is directly affected by the lubricant used. Numerous experiments indicate that 80 per cent mutton tallow and 20 per cent medium mineral lubricating oil give best results. Mixed at 150°F. and allowed to cool, it is about the consistency of soft soap and is applied with a swab. It works well on either die-casting or hot-pressing dies but lasts only about 10 per cent as long in the die-casting dies. Dies without lubricant lasted only 2 per cent as long as lubricated dies.

DEEP DRAWING MONEL METAL AND NICKEL

Practically the same rules as apply to steel in the reduction of diameter and depth of draw from initial blank govern monel or nickel. (Reduction here means diameter reduction, not area.) A well-balanced series of reductions on a double-action press (with pressure ring) would be 30 to 35 per cent on first operation, and 20 to 25 per cent on redraws. *Single-action* operation (without pressure ring) redraws from cup not over 20 per cent reduction. With very slight diameter reduction (less than 5 per cent) up to 30 per cent reduction in wall thickness may be obtained.

Dies.—Cast iron, heat-treated nickel-chrome cast iron, hardened steel chrome-plated, hard aluminum-bronze insert rings are satisfactory materials for dies. For very small work, tungsten-carbide steel dies are recommended. Carbon steel dies are not suitable.

Clearance.—Usually greater than for steel. Twenty-five per cent of thickness of metal is ample, and yet not excessive.

Radii.—Draw ring and punch nose are comparatively larger than those used for steel, six to ten times thickness of metal.

Lubrication.—Necessary and important. Lubricant should be free from sulphur or lead, otherwise any good lubricant would serve for light draws. Lubricant should be removed from metal before annealing. Best to determine where annealing is necessary by experiment before starting production depends on number of operations and work to be done after last draw. Network of small cracks indicates exhausted ductility. Annealing should be done before this occurs. When hardness of 35 to 40 Shore is reached, annealing is necessary before further work. Hardness is greatest near cupped edge.

Punching.—Punches are designed about 75 per cent stronger than for ordinary steel practice, with same clearance angle used for steel. Edges of holes are left considerably hardened.

BENDING SHEET STEEL

Allowances for 90-Degree Bends[1]

Considerable time can be saved in laying out sheet-metal parts with 90-degree bends by employing the tables presented. Location of the bend lines will be found accurate and much tiresome arithmetical computation can be avoided.

---

[1] Alf J. Abrahamsen, chief draftsman, Snead & Company.

Experience has shown that the neutral plane of a formed metal part (for gages of No. 10 to 24, inclusive) lies 20 per cent of the thickness from the inside face and 80 per cent of the thickness from the outside face. Dash lines in Figs. 31 and 32 represent the neutral planes of square and reverse bends. Since the neutral plane is one where no stretching of the metal takes place, it is obvious that the length of the formed part along the neutral plane will be the correct length, or cutting size, of the sheet.

It is an easy matter to compute the distance of the neutral plane from either side of the sheet. Similar computations can be made for each gage in common use. Finally, deductions or allowances for square bends or reverse bends, either singly or together, can be computed and placed in tables for ready reference.

Square Bends.—When the dimensions are given on the *outside* of a 90-degree form, the bend is considered square (see Fig. 31).

Reverse Bends.—When the dimensions are given on the *inside* of a 90-degree form, the bend is considered reverse (see Fig. 32).

Folds.—A fold, such as shown in Fig. 33, requires no deduction or allowance.

SAMPLE CALCULATIONS

To show how the tables are computed, consider two square bends, Fig. 31, in 16-gage sheet. The lengths of the three sides along the neutral axes are:

$$\begin{aligned} 2 - 2 \times 0.05 &= 1.90 \\ 1 - 0.05 &= 0.95 \\ 1 - 0.05 &= \underline{0.95} \\ & 3.80 \end{aligned}$$

Correct cutting length of the sheet is 3.80 inches, not 4 inches. The deduction to be made from the sum of the dimensions (which must all be on one side of the sheet) is 0.20 inch. This amount checks with that given in Table 24, for two square bends in 16-gage material.

Calculation of the cutting length for a part with reverse bends will show that material must be added to compensate for the bends. From Fig. 32 the lengths of the sides along the neutral plane are:

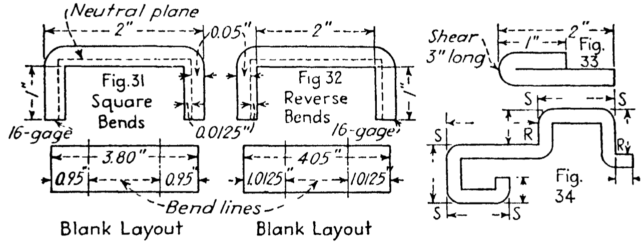
$$\begin{aligned} 2 + 2 \times 0.0125 &= 2.0250 \\ 1 + 0.0125 &= 1.0125 \\ 1 + 0.0125 &= \underline{1.0125} \\ & 4.0500 \end{aligned}$$

The amount to be added to the dimensions of the piece in order to get the correct cutting length is 0.05 inch. This value checks with the table for the allowance to be added when considering two reverse bends in 16-gage material. A blank layout, not to scale, is given for Figs. 31 and 32 to show the location of the bend lines.

Other features of Table 24 are a column of fractions and decimal equivalents and a column of the weights of sheet steel per square foot in gages Nos. 10 to 24 inclusive.

SQUARE AND REVERSE BENDS

Tables of deductions or allowances for combinations of square and reverse bends, Fig. 34, are given in Table 25. These tables are also based on gages Nos. 10 to 24, inclusive. They are set up to give the answer directly for combinations of from one square bend and one reverse bend to eight square bends and six reverse bends, thus taking in practically every case that will come up. In addition, values are given for the condition of no square bend and one reverse bend, and *vice versa*. The zeros in the headings indicate the absence of one or the other kind of bend.



FIGS. 31 to 34.—Square Bends in Sheet Steel

In the third horizontal row of figures in the headings, one will see a tabulation of constants. These can be used to find the allowance or deduction when the gage is not United States Standard. The actual thickness of the metal is multiplied by the constant to get the figure directly.

The figures given in Table 25 are actually the algebraic sum of the allowances or deductions for the individual bends. In some cases the result is positive and is indicated by a plus sign, meaning that this amount must be added to the dimensions on the piece. Where no plus sign is given, the figure must be deducted from the sum of the dimensions.

Bend Radii for Steel Tubing[1]

MANDREL BENDS

There are two types of bends; the mandrel bend and a bend made without a mandrel. The equipment used for making a mandrel bend consists of a machine to which are attached a bending die and mandrel holder and the necessary jaws and clamps to grip the tube while being bent. The tube is pushed over the mandrel, or the mandrel is inserted into the tube mechanically. The better grade of bends is made by this process, but as the tools are expensive and the operations slow, their cost is somewhat high. Mandrel bends are used only when the metal must be kept smooth. The reduction in diameter in the vertical plane is very slight, and the bend is free

[1] The Formed Steel Tube Institute.

TABLE 24.—SQUARE AND REVERSE BENDS

To determine cutting size of sheet steel: (1) add all the dimensions which must be on one side of sheet; (2) then deduct for square bends or add for reverse bends the dimension in the table which corresponds to the number of bends. See Figs. 31 and 32.

U.S.S. Gage		Deduct for Square Bends										Location of Bend Line	
Number	Equivalent	1	2	3	4	5	6	7	8	9	10	0.2*t*	0.8*t*
24	0.025	0.04	0.08	0.12	0.16	0.20	0.24	0.28	0.32	0.36	0.40	0.0050	0.0200
22	0.03125	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.00625	0.0250
20	0.0375	0.06	0.12	0.18	0.24	0.30	0.36	0.42	0.48	0.54	0.60	0.0075	0.0300
18	0.05	0.08	0.16	0.24	0.32	0.40	0.48	0.56	0.64	0.72	0.80	0.0100	0.0400
16	0.0625	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	0.0125	0.0500
14	0.0781	0.125	0.25	0.375	0.50	0.625	0.75	0.875	1.00	1.125	1.25	0.0156	0.0625
13	0.09375	0.15	0.30	0.45	0.60	0.75	0.90	1.05	1.20	1.35	1.50	0.01875	0.0750
12	0.1094	0.175	0.35	0.525	0.70	0.875	1.05	1.225	1.40	1.575	1.75	0.0219	0.0875
11	0.125	0.20	0.40	0.60	0.80	1.00	1.20	1.40	1.60	1.80	2.00	0.0250	0.1000
10	0.1406	0.225	0.45	0.675	0.90	1.125	1.35	1.575	1.80	2.025	2.25	0.0281	0.1125
		Add for Reverse Bends										Weight per Square Foot, 480 pounds = 1 Cubic Foot	
24	0.025	0.010	0.020	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	1.00 pound	
22	0.03125	0.0125	0.025	0.0375	0.05	0.0625	0.075	0.0875	0.10	0.1125	0.125	1.25	
20	0.0375	0.015	0.03	0.045	0.06	0.075	0.09	0.105	0.12	0.135	0.15	1.50	
18	0.05	0.020	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20	2.00	
16	0.0625	0.025	0.05	0.075	0.10	0.125	0.150	0.175	0.20	0.225	0.25	2.50	
14	0.0781	0.03125	0.0625	0.09375	0.125	0.156	0.187	0.218	0.25	0.281	0.312	3.125	
13	0.09375	0.0375	0.075	0.1125	0.15	0.1875	0.225	0.262	0.30	0.337	0.375	3.75	
12	0.1094	0.04375	0.0875	0.1312	0.175	0.2185	0.262	0.306	0.35	0.394	0.4375	4.375	
11	0.125	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	5.00	
10	0.1406	0.05625	0.1125	0.1687	0.225	0.281	0.3375	0.394	0.45	0.506	0.562	5.625	

TABLE 25.—SQUARE AND REVERSE BENDS.—*Continued*

To determine cutting size of sheet steel: (1) add all the dimensions which must be on one side of sheet; (2) then deduct the dimension in the table which corresponds to the allowance for the combination of the square bends and reverse bends under consideration. See Fig. 34.

Square		0	1							0	2						
Reverse		1	0	1	2	3	4	5	6	2	0	1	2	3	4	5	6
		Constant →															
Gage	Decimal	+0.40	1.60	1.20	0.80	0.40	0.00	0.40	0.80	+0.80	3.20	2.80	2.40	2.00	1.60	1.20	0.80
24	0.025	+0.010	0.04	0.03	0.02	0.01	....	+0.01	+0.02	+0.020	0.08	0.07	0.06	0.05	0.04	0.03	0.02
22	0.03125	+0.0125	0.05	0.038	0.025	0.013	....	+0.0125	+0.025	+0.025	0.10	0.088	0.075	0.063	0.05	0.038	0.025
20	0.0375	+0.015	0.06	0.045	0.03	0.015	....	+0.015	+0.03	+0.03	0.12	0.105	0.09	0.075	0.06	0.045	0.03
18	0.05	+0.020	0.08	0.06	0.04	0.02	....	+0.02	+0.04	+0.04	0.16	0.14	0.12	0.10	0.08	0.06	0.04
16	0.0625	+0.025	0.10	0.075	0.05	0.025	....	+0.025	+0.05	+0.05	0.20	0.175	0.15	0.125	0.10	0.075	0.05
14	0.0781	+0.03125	0.125	0.094	0.063	0.032	....	+0.031	+0.062	+0.0625	0.25	0.219	0.187	0.156	0.125	0.094	0.063
13	0.09375	+0.0375	0.15	0.113	0.075	0.038	....	+0.037	+0.075	+0.075	0.30	0.263	0.225	0.188	0.15	0.113	0.075
12	0.1094	+0.04375	0.175	0.132	0.088	0.044	....	+0.043	+0.087	+0.0875	0.35	0.307	0.263	0.219	0.175	0.132	0.088
11	0.125	+0.05	0.20	0.15	0.10	0.05	....	+0.05	+0.10	+0.10	0.40	0.35	0.30	0.25	0.20	0.15	0.10
10	0.1406	+0.05625	0.225	0.169	0.123	0.057	....	+0.056	+0.1125	+0.1125	0.45	0.394	0.338	0.282	0.225	0.169	0.113

Square		0	3							0	4						
Reverse		3	0	1	2	3	4	5	6	4	0	1	2	3	4	5	6
		Constant →															
Gage	Decimal	+1.20	4.80	4.40	4.00	3.60	3.20	2.80	2.40	+1.60	6.40	6.00	5.60	5.20	4.80	4.40	4.00
24	0.025	+0.03	0.12	0.11	0.10	0.09	0.08	0.07	0.06	+0.04	0.16	0.15	0.14	0.13	0.12	0.11	0.10
22	0.03125	+0.0375	0.15	0.138	0.125	0.113	0.10	0.088	0.075	+0.05	0.20	0.188	0.175	0.163	0.15	0.138	0.125
20	0.0375	+0.045	0.18	0.165	0.15	0.135	0.12	0.105	0.09	+0.06	0.24	0.225	0.21	0.195	0.18	0.165	0.15
18	0.05	+0.06	0.24	0.22	0.20	0.18	0.16	0.14	0.12	+0.08	0.32	0.30	0.28	0.26	0.24	0.22	0.20
16	0.0625	+0.075	0.30	0.275	0.25	0.225	0.20	0.175	0.15	+0.10	0.40	0.375	0.35	0.325	0.30	0.275	0.25
14	0.0781	+0.09375	0.375	0.344	0.313	0.282	0.25	0.219	0.188	+0.125	0.50	0.469	0.438	0.407	0.375	0.344	0.313
13	0.09375	+0.1125	0.45	0.412	0.375	0.338	0.30	0.263	0.225	+0.15	0.60	0.563	0.525	0.488	0.45	0.413	0.375
12	0.1094	+0.1312	0.525	0.482	0.438	0.394	0.35	0.307	0.263	+0.175	0.70	0.657	0.613	0.569	0.525	0.482	0.438
11	0.125	+0.15	0.60	0.55	0.50	0.45	0.40	0.35	0.30	+0.20	0.80	0.75	0.70	0.65	0.60	0.55	0.50
10	0.1406	+0.1687	0.675	0.619	0.563	0.507	0.45	0.394	0.338	+0.225	0.90	0.844	0.788	0.732	0.675	0.619	0.563

TABLE 25.—SQUARE AND REVERSE BENDS.—*Continued*

Square		0	5							0	6						
Reverse		5	0	1	2	3	4	5	6	6	0	1	2	3	4	5	6
		Constant →															
Gage	Decimal	+2.00	8.00	7.60	7.20	6.80	6.40	6.00	5.60	+2.40	9.60	9.20	8.80	8.40	8.00	7.60	7.20
24	0.025	+0.05	0.20	0.19	0.18	0.17	0.16	0.15	0.14	+0.06	0.24	0.23	0.22	0.21	0.20	0.19	0.18
22	0.03125	+0.0625	0.25	0.238	0.225	0.213	0.20	0.188	0.175	+0.075	0.30	0.288	0.275	0.263	0.25	0.238	0.225
20	0.0375	+0.075	0.30	0.285	0.27	0.255	0.24	0.225	0.21	+0.09	0.36	0.345	0.33	0.315	0.30	0.285	0.27
18	0.05	+0.10	0.40	0.38	0.36	0.34	0.32	0.30	0.28	+0.12	0.48	0.46	0.44	0.42	0.40	0.38	0.36
16	0.0625	+0.125	0.50	0.475	0.45	0.425	0.40	0.375	0.35	+0.15	0.60	0.575	0.55	0.525	0.50	0.475	0.45
14	0.0781	+0.156	0.625	0.594	0.563	0.532	0.50	0.469	0.438	+0.187	0.75	0.72	0.688	0.657	0.625	0.594	0.563
13	0.09375	+0.1875	0.75	0.713	0.675	0.638	0.60	0.563	0.525	+0.225	0.90	0.862	0.825	0.788	0.75	0.713	0.675
12	0.1094	+0.2185	0.875	0.832	0.788	0.744	0.70	0.657	0.613	+0.262	1.05	1.007	0.963	0.919	0.875	0.832	0.788
11	0.125	+0.25	1.00	0.95	0.90	0.85	0.80	0.75	0.70	+0.30	1.20	1.15	1.10	1.05	1.00	0.95	0.90
10	0.1406	+0.281	1.125	1.069	1.013	0.957	0.90	0.844	0.788	0.3375	1.35	1.29	1.24	1.182	1.125	1.069	1.013

Square		0	7							0	8						
Reverse		7	0	1	2	3	4	5	6	8	0	1	2	3	4	5	6
		Constant →															
Gage	Decimal	+2.60	11.20	10.80	10.40	10.00	9.60	9.20	8.80	+3.00	12.80	12.40	12.00	11.60	11.20	10.80	10.40
24	0.025	+0.07	0.28	0.27	0.26	0.25	0.24	0.23	0.22	+0.08	0.32	0.31	0.30	0.29	0.28	0.27	0.26
22	0.03125	+0.0875	0.35	0.338	0.325	0.313	0.30	0.288	0.275	+0.10	0.40	0.388	0.375	0.363	0.35	0.338	0.325
20	0.0375	+0.105	0.42	0.405	0.39	0.375	0.36	0.345	0.33	+0.12	0.48	0.465	0.45	0.435	0.42	0.405	0.39
18	0.05	+0.14	0.56	0.54	0.52	0.50	0.48	0.46	0.44	+0.16	0.64	0.62	0.60	0.58	0.56	0.54	0.52
16	0.0625	+0.175	0.70	0.675	0.65	0.625	0.60	0.575	0.55	+0.20	0.80	0.775	0.75	0.725	0.70	0.675	0.65
14	0.0781	+0.218	0.875	0.844	0.812	0.782	0.75	0.72	0.688	+0.25	1.00	0.969	0.938	0.906	0.875	0.844	0.812
13	0.09375	+0.262	1.05	1.013	0.975	0.938	0.90	0.862	0.875	+0.30	1.20	1.163	1.125	1.088	1.05	1.013	0.975
12	0.1094	+0.306	1.225	1.182	1.138	1.094	1.05	1.007	0.963	+0.35	1.40	1.356	1.313	1.269	1.225	1.182	1.138
11	0.125	+0.35	1.40	1.35	1.30	1.25	1.20	1.15	1.10	+0.40	1.60	1.55	1.50	1.45	1.40	1.35	1.30
10	0.1406	+0.394	1.575	1.518	1.462	1.407	1.35	1.29	1.24	+0.45	1.80	1.744	1.688	1.63	1.575	1.518	1.462

from wrinkles. In the light gages and for small radii, it is difficult to make bends of this type that are wholly free from wrinkle "shadows" so the radii of Table 26 should be used whenever possible.

TABLE 26.—MINIMUM RADII FOR MANDREL BENDS

O.D.	B.W. Gage	Minimum Radius, in Inches
½ to ⅞	16	1½ × O.D.
½ to ⅞	18	2 × O.D.
½ to ⅞	20	2½ × O.D.
1 to 2¼	14	1½ × O.D.
1 to 2¼	16	2 × O.D.
1 to 2¼	18	2½ × O.D.
1 to 2¼	20	3 × O.D.
2½ to 3¼	14	2 × O.D.
2½ to 3¼	16	2½ × O.D.
2½ to 3¼	18	3 × O.D.
2½	20	3½ × O.D.
3½ to 4	14	3½ × O.D.
3½ to 4	16	4 × O.D.
3½	18	4½ × O.D.

Reduction in diameter of the vertical plane 120 per cent of the gage—maximum.

Distance between bends

Bends in same plane	1½ × O.D.
Bends in different plane	2½ × O.D.

Distance between bends is defined as that distance between center point of radii plus the sum of the radii.

Distance of bends from end of tube:

In order to maintain true diameter of tube at the end, the center point of the bend must be located twice the diameter from the end plus the radius.

Sized ends: Ends can be sized when tolerances are closer than the tolerance for flash in grade of straight tube involved.

BENDING WITHOUT A MANDREL

There are numerous methods of making a bend without a mandrel, but the results are similar. The tools required are inexpensive and can be used over a wide range of angles, and the operation is rapid. In making a bend without a mandrel the dies must be somewhat smaller than the tube in order to support the metal, and to keep it from wrinkling. There is a reduction in diameter in the vertical plane, but the tube is free from wrinkles.

Although it may be possible to produce bends of smaller radii than tabulated in Table 27 and with radii closer together and other features, the bends become more costly to produce.

TABLE 27.—MINIMUM RADII FOR BENDS WITHOUT MANDREL

Diameter, in Inches	B.W. Gage	Minimum Radius, in Inches
$\frac{3}{4}$	14	2.0682
	16	2.1244
	20	2.2175
1	14	2.8436
	16	2.8998
	18	2.9495
	20	2.9928
$1\frac{1}{2}$	14	4.3942
	16	4.4505
	18	4.5002
	20	4.5435
2	14	5.9449
	16	6.0012
	18	6.0509
	20	6.0942
$2\frac{1}{2}$	14	7.4956
	16	7.5519
	18	7.6016
	20	7.6449
3	14	9.0463
	16	9.1026
	18	9.1523
	20	9.1956

Reduction in diameter of the vertical plane, $12\frac{1}{2}$ per cent of the outside diameter.

Distance between Bends

Bends in same plane	1 × O.D.
Bends in different plane	3 × O.D.

Other data on distance between bends and on tools are the same as for Table 26.

The minimum radius will be determined by the following formula:

$$L = \frac{0.2468\pi(D^2 - d^2)}{g}$$

where L = center-line radius.
D = outside diameter.
d = inside diameter.
g = gage.

Bending Thin-Walled Tube

Thin-walled tubes can be bent without kinking if they are filled with a suitable material. Tar, pitch, and resin have been used, but it is not always easy to remove the material which must be heated.

Although it can usually be melted out, it is apt to leave a thin film inside which may interfere with the use of the tube.

Fine sand is sometimes used, but it is more satisfactory where the wall of the tube is fairly heavy since it is very hard to fill the tube tight enough or to hold the sand during the bend and small kinks are apt to be formed during the bending.

Walter C. Smith, metallurgist of the Cerro de Pasco Copper Corporation, advises the use of Wood's metal for this purpose. This metal is made of 50 parts of bismuth, 24 of lead, 14 of tin, and 12 of cadmium, and melts at about 160°F., or less than the heat of boiling water. It can be bought in 10-pound ingots.

The tube to be bent is closed at one end by a cork and warmed with a blow torch or boiling water or steam and the melted metal is poured in. When cool it is bent as desired and the metal then removed by heating in steam or hot water. It should not be overheated as it may tin the inside of the tube. The alloy may be used repeatedly unless it is overheated, when it forms a dross and gives the alloy higher melting point.

Handy Sheet-Metal Tables

As the sheet-metal worker is often required to construct cans and tanks that will hold a given quantity, the following tables will be helpful:

SHEET-METAL CANS AND TANKS

Gallons	Diameter, in Inches	Height, in Inches	Gallons	Diameter, in Inches	Height, in Inches
1	6¼	6¼	50	20½	35
2	8½	8¾	55	21¼	36
3	9	11½	60	22	37
5	10½	13¾	65	22½	38
6	11½	13½	70	23	40
8	13½	13½	75	23½	40
10	13½	16½	80	24½	40
15	15½	19	85	25	40
20	17½	19½	90	24½	45
20	16	23	95	25	45
25	18	23	100	26	45
30	18½	26½	125	27½	50
35	18½	30½	150	29	52½
40	18¾	34	175	30	57½
45	19½	35	200	30¾	64

MEASURING-CUP DIMENSIONS

Size	Diameter, in Inches	Height, in Inches
¼ pint	2 9/16	2 15/16
½ pint	2¾	2¾
1 pint	3	3½
1 quart	3 9/16	5¾
Drinking cup	3	2½
Drinking cup	3⅝	2¾

DIMENSIONS OF FLARING MEASURES

This schedule is one that is commonly used by sheet-metal workers in commercial shops.

Size	Top Diameter, in Inches	Bottom Diameter, in Inches	Height, in Inches
¼ pint	2 1/16	2¼	2¼
½ pint	2¼	2½	2⅜
1 pint	2 11/16	3	4 9/16
1 quart	3¼	4	5 7/16
½ gallon	3½	5 3/16	7¾
1 gallon	5	6½	8⅞
2 gallon	6¼	8¾	9¾
3 gallon	8	10½	10¼
4 gallon	8½	11	12 5/16
5 gallon	9½	12½	12 1/16

FLARING-PAN DIMENSIONS

These standard sizes and dimensions of flaring pans may be constructed with the least waste of material.

Size	Diameter of Top, in Inches	Diameter of Bottom, in Inches	Height, in Inches
1 pint	5¾	4	2⅜
1 quart	6¼	4¾	2⅝
3 pint	8⅛	6⅜	2½
2 quart	8⅝	6⅛	3½
6 quart	12¾	9	4
10 quart	14¾	9⅜	4⅛

CONDUCTOR PIPE DIMENSIONS

Dimensions for cutting sheet for sizes of plain pipe that are most common in use; ¾ inch has been allowed for lock seam.

Round

Pipe size, in inches	1½	2	2½	3	4
Cut sheet, in inches	5½	7	8¼	10¼	13⅜

Square

Size 2 in inches	Dimensions, 1¾ × 2¼ inches	Cut Sheet, 8¾ inches
Size 3 in inches	Dimensions, 2 × 3 inches	Cut Sheet, 10¾ inches

BRIGHT COKE TINPLATE[1]

The base of this plate is best soft steel, either Bessemer or open-hearth, made especially for tinplating purposes. The word coke is a trade term indicating finish. The trade has retained it from the time when high-grade tinplates were made from charcoal iron and lower grades from coke iron. Hence, plates with lighter coating are called coke tin. Bright coke tin is used for making furnace pipes, as well as cans or containers for fish, fruit, vegetables, etc.

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[1] A. M. Castle Company.

Size Sheets, in Inches	Trade Term or Basis, Weight, in Pounds	Nearest U. S. Standard Gage	Symbol	Sheets per Box	Weight per Square Foot	Weight per Box	
						Net	Gross
20 × 26½	90	32		112	0.413	170	182
20 × 28	90	32		112	0.413	180	192
20 × 29½	90	32		112	0.413	189	201
24 × 28	90	32		112	0.413	216	228
20 × 26½	100	30½	I.C.L.	112	0.459	189	201
20 × 28	100	30½	I.C.L.	112	0.459	200	212
20 × 28	107	30	I.C.	112	0.491	214	226
20 × 32½	107	30	I.C.	112	0.491	248	260
20 × 39½	107	30	I.C.	56	0.491	151	163
24 × 28	107	30	I.C.	112	0.491	257	269
24 × 29½	107	30	I.C.	112	0.491	271	284
24 × 32½	107	30	I.C.	56	0.491	150	163
24 × 39½	107	30	I.C.	56	0.491	181	194

BRIGHT CHARCOAL TINPLATE[1]

Bright charcoal tin is coated with pure tin and is used for making vessels for permanent use. It is in various weights of coating according to the purpose for which the material is to be used. Each additional X indicates approximately one gage heavier base metal, and each additional A an additional coating of tin.

Size Sheets, Inches	Trade Term	Nearest U. S. Standard Gage	Coating	Sheets per Box	Weight per Square Foot	Weight per Box	
						Net	Gross
20 × 28	1X	28	2A	112	0.620	258	270
20 × 28	1X	28	3A	112	0.620	258	270
20 × 28	2X	26½	3A	56	0.712	144	156
20 × 28	3X	25½	3A	56	0.804	186	198
20 × 28	4X	25	3A	56	0.895	203	215
20 × 28	4X	25	5A	56	0.895	203	215

Terneplate is a kind of iron plate made by coating sheet iron with an alloy of tin and lead.

To "terne" means to coat with an alloy of tin and lead, or to make with terneplate.

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[1] A. M. Castle Company.

TABLE 27a.—DESIRABLE BEND RADII FOR ALUMINUM SHEET

Material	Thickness of Sheet													
	0.012	0.016	0.020	0.025	0.032	0.040	0.051	0.064	0.081	0.091	0.102	0.123	0.156	0.187
24SO	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{7}{32}$	$\frac{7}{32}$	$\frac{7}{32}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{5}{16}$
24ST	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{7}{32}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$
24SRT	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{7}{32}$	$\frac{7}{32}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$
3SO	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{7}{32}$	$\frac{7}{32}$	$\frac{5}{16}$	$\frac{5}{16}$
52SO	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{7}{32}$	$\frac{7}{32}$	$\frac{5}{16}$	$\frac{5}{16}$
3S–$\frac{1}{2}$H	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{7}{32}$	$\frac{7}{32}$	$\frac{5}{16}$	$\frac{5}{16}$
52S–$\frac{1}{2}$H	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{7}{32}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$

NOTE: Parts made from 24SO should specify 24ST bend radii wherever possible. For drop hammer or deep drawn parts use the largest possible radii consistent with design requirements.

ALUMINUM ALLOYS

In some cases the minimum bend radii for various aluminum alloys are not applicable to all methods of forming, and it is, therefore, advisable to use a radius wherever possible that has a wider application, that is, for use on either the power brake, Hydro-Press or the punch press. Such radii are shown in Table 27*a*.

Recent developments in the handling of ST material have made available smaller radii than those formerly used for some applications, and the absolute minimum will depend on the design of the part and the method to be used in its fabrication.

FERROUS ALLOYS

X-4130 steel can be safely formed to the radii in Table 27*b*.

TABLE 27*b*.—DESIRABLE COLD BEND RADII FOR X-4130 NORMALIZED STEEL

Gage	0.025	0.035	0.050	0.062	0.078	0.093	0.125	0.156	0.187	0.250
Radii	3/32	1/8	5/32	3/16	1/4	9/32	3/8	15/32	9/16	3/4

NOTE: Drawings of parts calling for minimum radii should specify that the bend must be normal to the direction of grain and that the edges of the parts must be burred. In some cases, it may be necessary to anneal normalized sheets before forming and when this occurs the drawings shall carry the note "Anneal before forming, normalize after forming."

TABLE 27*c*.—DESIRABLE BEND FOR STAINLESS STEEL AND INCONEL

Alloy	0.012	0.020	0.025	0.030	0.042	0.050	0.062	0.120	0.187
302—1A	1/16	1/16	1/16	1/16	3/32	1/8	1/8	1/4	3/8
302—½H	1/16	1/16	1/16	1/16	3/32	1/8	1/8	1/4	3/8
321—1A	1/16	1/16	1/16	1/16	3/32	1/8	1/8	1/4	3/8
347—1A	1/16	1/16	1/16	1/16	3/32	1/8	1/8	1/4	3/8
Inconel—1A	1/16	1/16	1/16	1/16	3/32	1/8	1/8	1/4	3/8
302-½H	3/32	1/8	5/32	3/16	1/4	5/16	3/8	3/4	1 1/8
302 H	3/32	1/8	5/32	7/32	9/32	11/32	3/8	3/4	1 1/8

PROPOSED STANDARD SIZES FOR AIRCRAFT TUBING

Rapid increase in the number of sizes of steel aircraft tubing specified by designers since the start of the rearmament program has made it desirable to draw up a list of proposed standard sizes. The Army-Navy Aeronautical Design Standard, June, 1940, listed 146 items, 3/16 to 4¾ inches outside diameter by 0.022 to 0.188 inch wall thickness. In 1942 the steel tubing industry was asked to make about 600 round sizes in X-4130 and over 200 round sizes in SAE 1025 material (see page 640*g*).

John W. Offutt and David T. Marvel, National Tube Company, United States Steel Corporation subsidiary, state that a detailed study of orders received in that year by four manufacturers showed requirements for 328 sizes, but of 33,000,000 feet of tubing involved, some 95 per cent was covered by 205 sizes. This list of sizes is tabulated in Table 27*d*, and is submitted with the approval of the National Aircraft Standards Committee as a proposed working standard, which may be followed without hardship to either design or production.

It is recognized that the aircraft manufacturer cannot adhere strictly to this list, but if he does so as much as possible the benefits will be better deliveries and lower prices. When 95 per cent of all orders are for standard sizes, consumers' orders can be grouped, thus permitting long mill runs on individual sizes, and creating a stock reservoir that can be tapped in emergencies. Further, standardization of sizes permits stocking of finished tubing in both mill stocks and distributors' warehouses when conditions of supply and demand permit.

Another advantage to the consumer is that jigs and fixtures, as well as fittings, will be reduced in proportion to the number of tubing sizes.

Special sizes will still be available, and where quantities are sufficiently large, there is no objection on the part of the tubing manufacturer to accepting such orders.

Aircraft tubing is a special grade of cold-drawn mechanical tubing. Structural tubing is specified in plain carbon (SAE-1025) and chrome-molybdenum (SAE X-4130) steel, the latter being used in practically all but the lighter trainer-type planes. Because of difficulties in securing ample supplies of X-4130 steel, chrome-nickel-molybdenum (NE-8630) steel is being used as an alternate material. Equipment and tools used in the whole range of regular mechanical tubing have been available for manufacture of aircraft tubing—that is, $\frac{1}{16}$ to $10\frac{3}{4}$ inches outside diameter and wall thickness from 0.004 to $1\frac{5}{8}$ inch thick. Obviously, aircraft designers have not required this great range, and for the reasons cited above they should stick to the tabulated 205 sizes unless there are compelling reasons for a special size. The proposed list of sizes does not apply to tubing used in landing gear, engine parts, propeller blades and pressure lines.

METHODS FOR CUTTING AIRCRAFT SHEET METAL[1]

Every sheet-metal part for aircraft has some cutting operation performed upon it. Parts must be so designed that they can be cut on one machine and with one operation if possible. Bend reliefs and notches are the most frequent violations of this rule.

Consideration must also be given to adapting the part to manufacture on the most efficient type of production machine. The probable volume of parts affects the decision. Comparative efficiencies of seven types of machines are listed, together with their limitations for cutting various metals.

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[1] Courtesy of Douglas Aircraft Company.

Routing

MACHINE EFFICIENCY
A = Excellent B = Good C = Fair D = Poor

Number of Parts	Cost	Speed	Accuracy
1 to 5	B	B	A
5 to 50	A	A	A
50 to 500	A	A	A
500 and up	A	A	A

NOTES.—Setup cost is low. Templet cost is low. Operating cost is moderate.

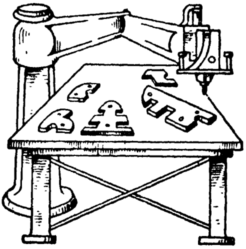


FIG. 35.—Router. This Trims Stacks of Sheet Metal to Desired Shape.

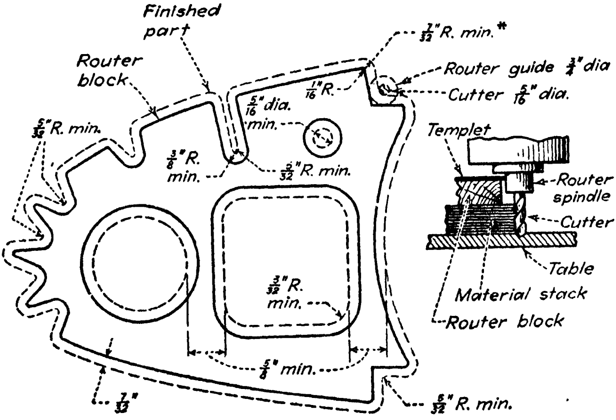


FIG. 36.—Router Block Limitations. Absolute Minimum = $\frac{5}{32}$ Inch *R*. Recommended $\frac{9}{32}$ Inch *R* Eliminates Sharp Corners on Router Block.

MATERIALS CUT

Aluminum, aluminum alloy, magnesium alloy, copper, and other "soft" metals may be cut.

Corrosion-resistant steel ruins most router bits. Used only in special instances.

DESIGN CONSIDERATIONS

If any cutting operations must be done on router, the entire part should be adapted for router.

Routing is more expensive than straight shearing and/or punch press notching where punch dies are on hand, but is the least expensive method of blanking large or complicated shapes.

If large numbers of small parts are to be made, consider the possibility of combination punch-press blanking and forming.

Profiling

MACHINE EFFICIENCY

A = Excellent B = Good C = Fair D = Poor

Number of Parts	Cost	Speed	Accuracy
1 to 5	B	B	A
5 to 50	A	A	A
50 to 500	A	A	A
500 and up	B	B	A

NOTE.—Form block cost is small. Setup cost is slight. Operating cost is moderate.

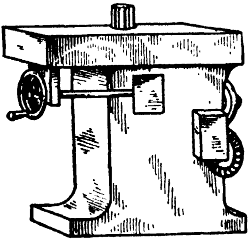


FIG. 37.—Specialized Routing Machine for Trimming Edges of Formed Sheet-Metal Parts.

MATERIALS CUT

Aluminum, dural, magnesium, and other "soft" metals, but not corrosion-resistant steel, and Inconel.

LIMITATIONS

Only limiting dimensions are:
  Max. thickness of material—¼ inch.
  Min. size inside radius cut—⅛ inch.

DESIGN CONSIDERATIONS

This is the most accurate method available for trimming irregular edges of formed parts.

Properties of Materials

ALUMINUM (2SO, 3SO)

Adaptable to plastic forming operations, including severe drawing. Has good ductility and good malleability. Does not have great strength, nor can it be heat-treated.

ALUMINUM ALLOY

Soft (17*SO*, 24*SO*).—Similar to aluminum but will not stand as severe cold working. Good malleability but poor ductility. When heat-treated, qualities approach but are not equal to those of hard stock.

Hard (17*ST*, 24*ST*).—Stronger, and has greater resiliency (springback) than soft stock. Elongation properties approximate those of soft stock, but this material has poorer ductility and malleability.

MAGNESIUM ALLOYS

Soft (*A or SO*).—More brittle than aluminum alloy, and therefore it must be formed at elevated temperatures (350 to 750°F.). When heated to these temperatures, the forming properties are similar to aluminum soft stock.

Hard (*H or SH*).—Very difficult to form when cold because of tendency to split. May be formed at elevated temperatures (350 to 750°F.), but insufficient information is available to predict forming ability.

CORROSION-RESISTING STEEL

Fully Annealed.—A corrosion and heat-resistant metal, having good elongation and forming qualities. Has tendency to work harden, and may require reannealing. Fair ductility, but poor malleability.

½ *Hard.*—A corrosion and heat-resistant metal, having great tensile strength but poor malleability and ductility.

Full Hard.—A corrosion and heat-resistant metal, having high impact and tensile strength, fair elongation, but poor ductility and malleability.

Sawing

MACHINE EFFICIENCY

A = Excellent B = Good C = Fair D = Poor

Number of Parts	Cost	Speed	Accuracy
1 to 5	A	A	B
5 to 50	A	A	B
50 to 500	A	A	B
500 and up	B	B	B

NOTE.—Setup cost is slight. Operating cost is moderate. Part must be filed or burred after sawing.

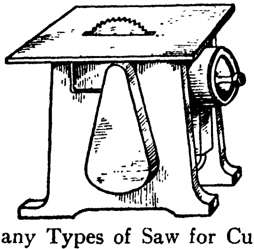


FIG. 38.—One of Many Types of Saw for Cutting Such Parts as Cannot Be Sheared.

TABLE 27*d*.—205 SIZES OF STEEL AIRCRAFT TUBING Recommended by National Aircraft Standards Committee (Dimensions in Inches)

Wall Thickness	Outside Diameter																						
	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2	2 1/4	2 1/2	2 3/4	3
0.022	22	22	22	22																			
0.028	28	28	28	28	28	28		28	28	28	28	28											
0.035	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35		35	35	35				
0.049	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49				
0.058		58	58	58	58	58		58	58	58	58	58	58	58	58	58	58	58	58	58			58
0.065		65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65
0.083				83	83	83		83	83	83	83	83	83	83	83	83	83	83	83	83	83	83	83
0.095			95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95
0.120						120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120
0.156								156	156	156	156	156	156	156	156	156	156	156	156	156	156	156	156
0.188								188	188	188	188	188	188	188	188	188	188	188	188	188	188	188	188
0.250									250		250	250	250		250		250	250	250	250	250	250	250
0.313													313				313		313	313			313
0.375													375	375							375	375	
0.500																						500	

MATERIALS CUT

All metals may be cut on one of several types of saws available within thickness limitations indicated below.

LIMITATIONS

MATERIAL	MAX. THICKNESS IN INCHES[1]
Aluminum & Dural	3
C.M. Steel	[illegible]
Cor. Resist. Steel	[illegible]
Inconel	[illegible]
Magnesium	3
Minimum practical radius	1½

[1] Single thickness or stacked material.

DESIGN CONSIDERATIONS

By means of various types of saws practically all types of cuts may be made in all commonly used metals.

Straight Shearing

MACHINE EFFICIENCY

A = Excellent, B = Good, C = Fair, D = Poor

Number of Parts	Cost	Speed	Accuracy
1 to 5	A	A	A
5 to 50	A	A	A
50 to 500	A	A	A
500 and up	A	A	A

NOTES.—No die cost. Setup cost is very little. Operating cost is moderate.

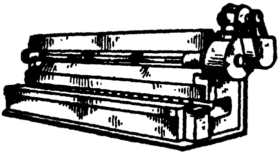


FIG. 39.—For Shearing Straight and Free Edges of Sheet Metal.

MATERIALS CUT

Will shear all metals within limits indicated in column.

DESIGN CONSIDERATIONS

Use of a straight shear is limited to straight and free edges only.

If cuts must be made on a part, and cannot be made on a punch press, it may be cheaper to design the item for production in one setup on a router.

LIMITATIONS
MAXIMUM LENGTH AND GAGE

Material	6 Inch Shear Max. Gage	10 Inch Shear Max. Gage	18 Inch Shear Max. Gage
Aluminum	0.312	0.218	0.218
SO	0.312	0.218	0.218
ST	0.312	0.218	0.218
MG	0.312	0.218	0.218
Cor. Resist. Steel	0.312	0.125	
CM Steel	0.312	0.187	
CR Steel	0.312	0.187	

Rotary Shearing

MACHINE EFFICIENCY

A = Excellent, B = Good, C = Fair, D = Poor

Number of Parts	Cost	Speed	Accuracy
1 to 5	A	A	C
5 to 50	B	B	C
50 to 500	C	C	C
500 and up	D	D	C

NOTES.—No die or setup cost. Operating cost is moderate.

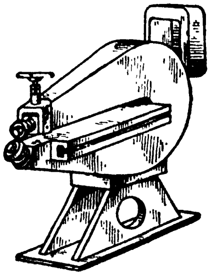


FIG. 40.—For Shearing Irregular Shapes of Sheet Metal.

MATERIALS CUT

Will shear all metals within limits indicated in table.

DESIGN CONSIDERATIONS

Minimum radius which may be sheared is 1½ inch. There is no maximum radius.

Rotary shears are a low production machine, used only for reworking parts, or in cases where few parts are required.

Machine usually leaves rough edge or burr on parts; therefore, it is poorly adapted to cutting parts for concave flanges, where edge condition is critical

LIMITATIONS
MAXIMUM GAGE AND LIMITING RADII

Material	Max. Gage	Min. Radius, in Inches	Max. Throat Clearance, in Inches
Aluminum	0.084	1½	84
SO	0.084	1½	84
ST	0.072	2	84
MG	0.072	1½	84
Cor. Resist. Steel	0.051	2	20
CM Steel	0.051	2	20
CR Steel	0.051	2	20

Punch-Press Shearing

MACHINE EFFICIENCY
A = Excellent, B = Good, C = Fair, D = Poor

Number of Parts	Cost	Speed	Accuracy
1 to 5	B[1]	B[1]	A
5 to 50	A	A	A
50 to 500	A	A	A
500 and up	A	A	A

NOTES.—Die cost is very high. Setup cost is moderate. Operating cost is low.

[1] Punch press cheapest and most efficient method if standard dies can be used; viz. standard notching die.

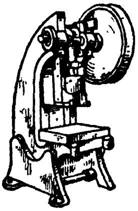


FIG. 41.—Punch Press, a High-Production Machine Capable of Blanking or Notching Large Numbers of Small Parts.

MATERIALS CUT

All materials may be sheared on a punch press.

DESIGN CONSIDERATIONS

Notches or other standard cutouts may best be formed by standard punch dies. Therefore, specify standard notches or cutouts wherever possible.

LIMITATIONS

Limitations of punch press operations are usually limitations of individual dies.

Hydro-Press Shearing

MACHINE EFFICIENCY

A = Excellent, B = Good, C = Fair, D = Poor

Number of Parts	Cost	Speed	Accuracy
1 to 5	C	C	B
5 to 50	C	B	B
50 to 500	B	B	B
500 and up	C	C	B

NOTES.—Die cost is moderate. Setup cost is low. Operating cost is moderate.

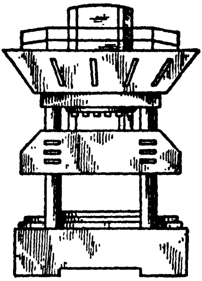
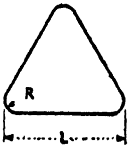
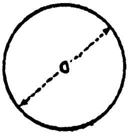


FIG. 42.—Hydro-Press. Primarily a Forming Machine but Adaptable to Form and Shear or Gang Shearing Operations.

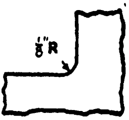
Minimum Dimensions—Shearing



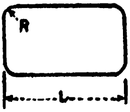
G	*D*
0.020	¾ Inch
0.032	1 Inch
0.040	1½ Inches



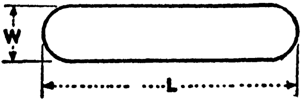
G	*L*	*R*
0.020	1½	⅛
0.032	1½	⅛
0.040	2½	8/16



Bond Relief Up to 0.040 Inch Inclusive.



G	*L*	*R*
0.020	1¼	⅛
0.032	1½	⅛
0.040	2	8/16



W limits for elongated holes are identical with those for round holes.

MATERIALS CUT

Aluminum (2SO, 3SO) and soft stock (24SO) only in gages up to 0.040 inch.

DESIGN CONSIDERATIONS

Typical applications of Hydro-Press shearing are:
- Where part is sheared and formed in same operation.
- Where large numbers of parts of same gage material are needed for same assembly.

All shapes may be cut on Hydro-Press within limits indicated.

Hydro-Press shearing results in combination shear and tension failure of metal. Therefore, edges must be dressed when subject to further stretching operations.

To design aircraft sheet metal parts for economical production, one must understand the machine selected to produce the part—its capabilities, limitations, efficiency in relation to other machines that might be used for the same purpose.

Parts formed from hard stock, 24STAL aluminum alloy, exhibit superior physical properties and corrosion resistance, and have certain manufacturing advantages as compared to pieces made from soft stock. Most hard stock fabrication is performed on power brakes, stretcher presses and roll forming machines at present.

Shrinking Machine

MACHINE EFFICIENCY

A = Excellent, B = Good, C = Fair, D = Poor

Number of Parts	Cost	Speed	Accuracy
1 to 5	A	A	C
5 to 50	A	A	C
50 to 500	B	B	C
500 and up	C	C	C

NOTES.—No die cost. No setup cost. Operating cost is moderate.

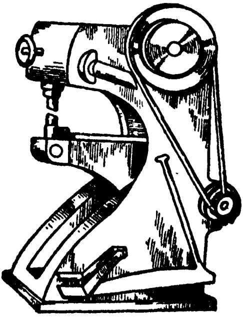


FIG. 43.—A Shrinking Machine, an Aid to Hand Forming.

MATERIALS FORMED

All commonly used metals may be formed on this machine, including lighter gages of stainless steel.

DESIGN CONSIDERATIONS

Parts are never designed to be formed on the shrinking machine. This machine is used only as an aid to handforming.

LIMITATIONS

Minimum flange radius, ¾ inch.

It is impossible to form all parts on a shrinking machine because it is a reworked punch press and may interfere with larger parts when shrinking certain areas.

Spinning

MACHINE EFFICIENCY

A = Excellent, B = Good, C = Fair, D = Poor

Number of Parts	Cost	Speed	Accuracy
1 to 5	A	A	B
5 to 50	A	A	B
50 to 500	A	A	B
500 and up	C	C	B

NOTES.—Tool cost is moderate, but dependent upon the shape of the part. Setup cost is small. Operating cost is moderate.

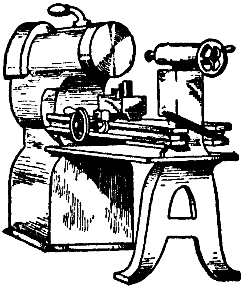


FIG. 44.—A Shrinking Lathe, Forming a Sheet of Metal into Revolute Shapes.

MATERIALS FORMED

Aluminum (2SO, 3SO) is the best material for spinning.

Aluminum Alloy:

Soft stock (24SO, 24SOAL) spins well, although it may have to be annealed during the operation. Alclad will nut rub off except in very severe spinning.

Hard stock (24ST, 24STAL) has not been spun successfully.

Magnesium alloy will probably form if heated to 400 to 500°F. during the forming operation.

Corrosion-resisting steel work hardens rapidly, but lighter gages in the annealed condition may be formed by reannealing during the spinning process.

DESIGN CONSIDERATIONS

Parts which lock on the die may be formed only on collapsible tools, which are considerably more expensive than a regular die.

Hard stock should never be specified.

Dimensions on spun parts should always be given to the concave side so they can be applied directly in making the spinning block.

Accuracy of finished parts is possible and close tolerances can be held, although widest tolerances consistent with usage of part should be specified.

LIMITATIONS

No size limitations are involved, except the swing of a given machine.

Hydro-Press

Although capable of shearing lighter metal, the Hydro-Press is primarily a stretching and bending machine. It is adaptable to forming beads, flanges, lightening holes and similar shapes from sheet metal.

MACHINE EFFICIENCY

A = Excellent, B = Good, C = Fair, D = Poor

Number of Parts	Cost	Speed	Accuracy
1 to 5	B	B	B
5 to 50	A	A	B
50 to 500	A	A	B
500 and up	A	A	B

NOTES.—Die cost is low. Setup cost is extremely low. Operating cost is low. Flexibility is very good.

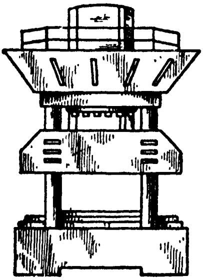


FIG. 45.—Hydro-Press for Forming.

MATERIALS FORMED

Aluminum (2SO, SO) has excellent forming characteristics, no appreciable springback, and is good for complicated draws.

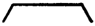
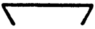
Aluminum alloy—soft stock (24SO, 24SOAL) has good forming characteristics, although it will elongate less than aluminum. Hard stock (24ST, 24STAL) is preferable because it eliminates the heat-treating operation. An objection is that greater pressure is needed, and excess springback causes the part to warp. Accordingly, only certain parts can, at present, be made from hard stock.

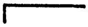
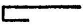
Magnesium alloy (MA, MH, AM3SO, AM3SH) has the same general characteristics as soft stock when formed on a hot plate.

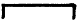
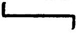
Corrosion-resisting steel (18-8) has good forming characteristics in annealed and in ¼ hard condition in lighter gages. It is impossible to form full-hard metal because of insufficient pressure.

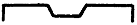
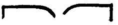
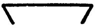
DESIGN CONSIDERATIONS

In designing for the Hydro-Press, the main problems are:
To form the part without splitting or wrinkling.
To form the part properly in one stroke without hand malleting.
To insure this, the following suggestions are given:

Design for open flanges  rather than closed flanges. .

Design for simple flanges  rather than  "C" flanges.

Use channel sections  rather than  Z sections.

Locate beads on same side as flanges.  In general, female bead dies form better than male bead dies. Form lightening holes in same direction as flanges.  Exception: Where closed flanges  have to be used, specify "direction of lightening hole optional."

LIMITATIONS

2,000-ton press (SM)—36- by 96-inch table
Rubber thickness, 6 inches.
Max. formed height of part, 3 inches.
5,000-ton press (SM)—50- by 168-inch table
Rubber thickness, 10 inches.
Max. formed height of part (depends on method of loading and type of die), 8 to 10 inches.
2,500-ton press (LB)—36- by 96-inch table
Rubber thickness, 10 inches.
Max. formed height of part, 8 to 10 inches.

Flanging Machine

MACHINE EFFICIENCY

A = Excellent, B = Good, C = Fair, D = Poor

Number of Parts	Cost	Speed	Accuracy
1 to 5	A	B	B
5 to 50	B	A	B
50 to 500	B	B	B
500 and up	D	C	B

NOTES.—No die cost. Setup cost is moderate. Operating cost is moderate.

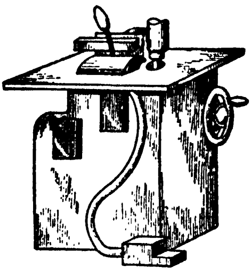


FIG. 46.—A Flanging Machine; Forms Straight C Flanges on All Radii.

MATERIALS FORMED

All sheet metals can be formed on flanging machines within their limiting bend radii.

DESIGN CONSIDERATIONS

Flanging machine is used mainly for C flanges which have been partly formed on Hydro-Press.

It is used also to bead wire.

The machine is actually an aid to hand forming of flanges which cannot be formed otherwise.

LIMITATIONS

Individual tools control limits of flanging machine.

Corrugating and Forming Rolls

MACHINE EFFICIENCY

A = Excellent, B = Good, C = Fair, D = Poor

Number of Parts	Cost	Speed	Accuracy
1 to 5	D	D	A
5 to 50	D	D	A
50 to 500	D	D	A
500 and up	B[1]	B[1]	A

NOTES.—Die cost is extremely high. Setup is extremely high. Operating cost is very low.

[1] If rolls are on hand, these costs and speeds should be rated "A."

Corrugations are made for stock.

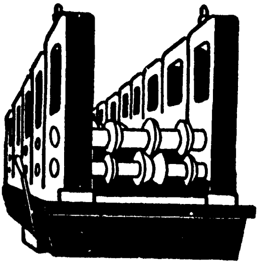


FIG. 47.—Corrugating and Forming Rolls. A Single-Purpose Machine for Making Corrugated or Hat Sections on a Production Basis.

MATERIALS FORMED

All commonly used metals may be formed on these machines, within the limiting bend radii of the metals used.

DESIGN CONSIDERATIONS

The first design consideration is to try to use standard corrugation which can be made with rolls on hand.

When less than 2000 full-sheet corrugations are needed, and rolls are not available, the part will probably be formed on power brake.

LIMITATIONS

The maximum width of flat sheet (developed width of corrugation) depends on machine capacity.

The maximum width of corrugated sheet is dependent upon corrugation dimensions.

There is no limit on length of sheets.

Stretcher Press

MACHINE EFFICIENCY

A = Excellent, B = Good, C = Fair, D = Poor

Number of Parts	Cost	Speed	Accuracy
1 to 5	C	B	B
5 to 50	A	A	B
50 to 500	A	A	B
500 and up	B	B	B

NOTES.—Die cost is moderate. Setup cost is moderate. Operating cost is moderate.

Experimental cost on new-type dies may be high.

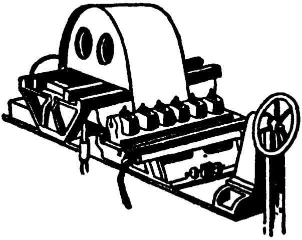


FIG. 48.—A Stretcher Press. A Machine for Forming Compound Contours in Sheet Metal through Stretching over a Form Block.

MATERIALS FORMED

Aluminum (2SO, 3SO) probably can be used satisfactorily, but harder materials are generally used to better advantage.

Aluminum alloy (24SO, 24ST) in both hard and soft grades may be used with equal facility. Use of hard stock is recommended because it eliminates the heat-treating operation. Stretching does not scratch Alclad.

Magnesium alloy—No stretcher press work has been done with magnesium but is probably feasible.

Corrosion-resisting steel (18-8) has very good forming qualities. Possible limitation might be power available for yielding stainless.

DESIGN CONSIDERATIONS

At present, sheet-metal skin contours, and other faired sheet-metal sections are the principal uses of the stretcher press.

Much larger areas may be included in a single contoured sheet than previously permitted by the Hydro-Press contouring method.

Contours may be formed to advantage with hard stock, thus eliminating the heat-treating operation.

Either right- or left-hand parts may be made with same die. Contoured parts may be "snapped through" to produce part of opposite hand (reverse contour).

To determine the sheet stock size to be specified, add allowance for gripping metal. This added material may represent a high percentage of material waste for smaller parts.

LIMITATIONS

	MAX.	MIN.
Length	20 to 25 ft.	24 in.
Width	86 in.	None

Minimum inside radius at the pull-line is 1½ inch.

Draw Bench

MACHINE EFFICIENCY

A = Excellent, B = Good, C = Fair, D = Poor

Number of Parts	Cost	Speed	Accuracy
1 to 5	D	D	A
5 to 50	C	C	A
50 to 500	A	B	A
500 and up	A	A	A

NOTES.—Die cost is moderate. Setup cost is moderate. Operating cost is moderate.

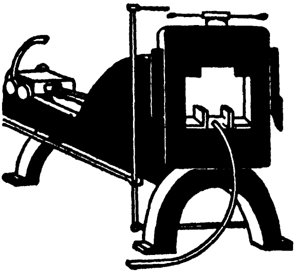


FIG. 49.—A Draw Bench. A Machine for Drawing Strip Stock into Formed Lengths.

MATERIALS FORMED

Aluminum (2SO, 3SO) may be drawn easily.

Aluminum alloy—Soft stock (17SO, 24SO) may be drawn easily. Hard stock (17ST, 24ST)—in the experimental stage.

Magnesium alloy (MA, MH, AM3SO, AM3SH) in experimental stage.

Corrosion-resisting steel may be drawn easily.

DESIGN CONSIDERATIONS

Specify standard sections wherever possible.

LIMITATIONS

In general, the same minimum bend radii may be used as for straight brake bends.

The limiting dimension for parts which must be heat-treated is usually the furnace length, although pieces 40 feet long can be drawn and then cut to suitable lengths for parts.

Drop Hammer

MACHINE EFFICIENCY

A = Excellent, B = Good, C = Fair, D = Poor

Number of Parts	Cost	Speed	Accuracy
1 to 5	C	C	B
5 to 50	B	B	B
50 to 500	C	B	B
500 and up	D	C	B

NOTES.—Die cost is fairly high. Setup cost is moderate. Operating cost is high per part.

Certain types of drop-hammer dies must be replaced after several hundred parts because of excessive wear.

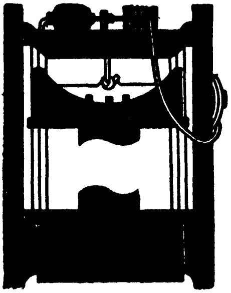


FIG. 50.—**A Drop Hammer.** A Low-Production Machine for Severe Forming by Drawing and Controlled-Compression Failure.

MATERIALS FORMED

Aluminum (2SO, 3SO) is the best metal for severe drawing operations.

Aluminum alloy—Soft stock 24SO, 24SOAL) is used for medium draws which can be made in one or two hits. Hard stock (24ST, 24STAL) is rarely used because of springback and work-hardening difficulties.

Magnesium alloy (MA, MH, AM3SO, AM3SH)—Good forming characteristics with heated sheet and dies.

Corrosion-resisting steel (18-8)—Excellent for drop hammer forming in annealed condition only. Hardened metal ruins dies except in very thin gages.

DESIGN CONSIDERATIONS

One does not design for the drop-hammer, but if the part has not been designed so that it will form on any other machine, the piece is adapted for drop-hammer production, viz:

Sharp bends, which cannot be formed on the Hydro-Press, necessitate forming entire part on drop hammer.

Since drop-hammer work involves some drawing action, sharp radii result in excessive work hardening, causing part to crack. Sharp radii also cause excessive die wear.

Symmetrical draws form better than do unsymmetrical shapes.

LIMITATIONS

There are no specific maximum forming limits for drop-hammer work—results depend on method of reduction, skill of the operator, and elongation of metal.

Contouring Rolls

MACHINE EFFICIENCY

A = Excellent, B = Good, C = Fair, D = Poor

Number of Parts	Cost	Speed	Accuracy
1 to 5	A	A	B
5 to 50	A	A	B
50 to 500	A	A	B
500 and up	B	B	B

NOTES.—No die cost. No setup cost. Operating cost is moderate.

All sheet metals can be formed on bending rolls, within their limiting bend radii.

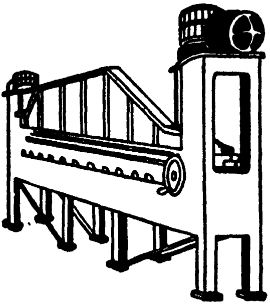


FIG. 51.—Contouring Rolls, Which Make Straight Contours in Sheet Metal.

DESIGN CONSIDERATIONS

Compound bends cannot be made on contouring rolls. Such bends must be made on the Hydro-Press, or by other, more costly methods.

It is extremely difficult to bend sheet metal in a complete circle to less than 2 inches radius.

Tapered roll sections may be formed without difficulty.

LIMITATIONS

Width, gage of stock, minimum radius of contour formed depend upon the size and power the machine installed. Usually there is no limit on the length of sheet that can be handled, unless formed to more than 180 degrees.

Deep-Draw Press

MACHINE EFFICIENCY

A = Excellent, B = Good, C = Fair, D = Poor

Number of Parts	Cost	Speed	Accuracy
1 to 5	C	C	A
5 to 50	C	B	A
50 to 500	B	A	A
500 and up	A	A	A

NOTES.—Die cost is high. Setup cost is high. Operating cost is low. Experimental cost is often very high.

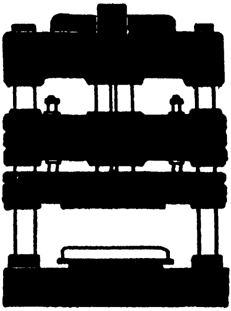


FIG. 52.—Deep-Draw Press. A Medium-Production Machine That Can Draw Parts by a Controlled Drawing Action.

MATERIALS FORMED

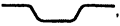
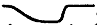
Aluminum (2SO, 3SO) has the best forming characteristics. Grade 52SO work hardens rapidly, and therefore is not as adaptable as other soft aluminum.

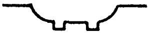
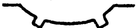
Aluminum alloy—Soft stock (24SO, 24SOAL) will form on limited draws, but work-hardens very rapidly. Hard stock (24ST, 24STAL) has excess springback, and rapidity of work-hardening prevents deep drawing.

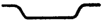
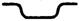
Magnesium alloy—No deep-drawing work on this metal has been done as yet, but appears feasible.

Corrosion-resisting steel (18-8) can be formed in the full-annealed condition only.

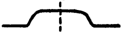
DESIGN CONSIDERATIONS

Part can be formed best if symmetrical. This , preferable this .

Holes can be formed only in direction of draw. This , not this .

Angle of draw should be symmetrical, and as wide as possible. This  preferable to .

Both inside and outside draw radii, as well as corner radii, are critical.

Consider whether right-hand part and left-hand part, or two similar parts, can be made in one draw, then cut in half .

Ductility of material affects success of draw; therefore specify only 2SO or 3SO for severe draws.

LIMITATIONS

For a 650-ton press of one type, the maximum die size is 58 × 119 inches; the maximum practical draw, 19 inches.

Punch Press

MACHINE EFFICIENCY

A = Excellent, B = Good, C = Fair, D = Poor

Number of Parts	Cost	Speed	Accuracy
1 to 5	D[1]	D[1]	A
5 to 50	D[1]	D[1]	A
50 to 500	B[1]	C[1]	A
500 and up	A	A	A

[1] Punch press cheapest and most efficient method if notching dies can be used.

NOTES.—Original die cost is very high. Set-up cost is moderate. Operating cost is very low.

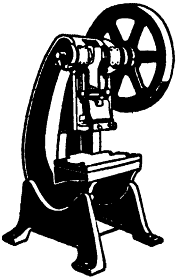


FIG. 53.—A Punch Press. A High-Production Machine Capable of Blanking, Forming, and Drawing Metals.

MATERIALS FORMED

Aluminum (2SO, 3SO) has excellent forming characteristics and is very good for draws.

Aluminum alloy (24SO, 24ST) in both hard and soft stock is used extensively. Hard stock is usually specified for simple blanking and forming operations; soft stock for more severe forming operations.

Magnesium alloy (MA, MH, AM3SO, AM3SH)—use of this metal has not been developed.

Corrosion-resisting steel (18-8) blanks and forms exceptionally well.

DESIGN CONSIDERATIONS

In designing any small sheet-metal part which is to be manufactured in large numbers, consider that some or all of part may be formed on a punch press. Therefore:

Specify standard notches, cutouts, bend reliefs, as these are all made by standard punch press dies.

Consider die clearance for all punching operations near flanges, beads, and joggles.

LIMITATIONS

Limitations of punch press operations are usually limitations of individual dies.

Power Brake

MACHINE EFFICIENCY

A = Excellent, B = Good, C = Fair, D = Poor

Number of Parts	Cost	Speed	Accuracy
1 to 5	A	A	B
5 to 50	A	A	B
50 to 500	A	A	B
500 and up	B	A	B

NOTES.—All standard dies used. Setup cost is low. Operating cost is moderate.

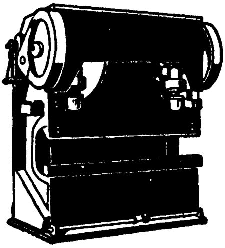


FIG. 54.—A Power Brake. A Medium-Production Machine for Forming Straight-Break Flanges and Similar Shapes.

MATERIALS CUT

Aluminum (2SO, 3SO) has excellent forming characteristics.

Aluminum alloy—Soft stock (24SO, 24SOAL) is easily bent to small radii. Hard stock (24ST, 24STAL) will form well, except that the part has to be overformed to allow for springback.

Magnesium alloy (MA, MH, AM3SO, AM3SH) is not particularly adapted to power brake forming, but may be done on large bend radii.

Corrosion-resisting steel (18-8) will form exceptionally well in all conditions of hardness.

DESIGN CONSIDERATIONS

The fundamental principle in designing for power brake is that the punch must be able to form the part without locking on the machine (including overforming angle for springback).

Minimum radius tends to mark the parts. Use slightly larger radius where this is possible.

LIMITATIONS

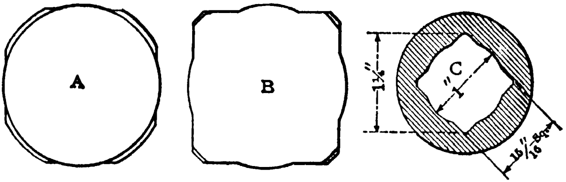
Minimum flange height depends upon material and bend radius. With 24SOAL and 24STAL in 0.025 inch gage, the height is $\frac{3}{16}$ for a $\frac{1}{16}$ inch radius; $\frac{5}{16}$ for a $\frac{1}{8}$ inch radius.

SECTION XIV

BROACHES AND BROACHING

Broaching is extending its field yearly. Originally used for round or irregular holes, it has replaced milling in many outside-finishing operations, such as the outside surfaces of automobile cylinder blocks and many smaller pieces.

The chip cut by each tooth varies from 0.001 to 0.007 inch, according to the material being cut and the accuracy required. The teeth are usually undercut from 6 to 10 degrees to give a curl to the chip, while the top clearance is about 30 degrees. Some English practice undercuts 25 degrees, having top nearly flat. The distance between teeth varies according to the length of the hole being broached, the spacing being larger for long holes so as not to have too many teeth engaged at once; three, for example, is a good number.



The First Chip **The Last Chip** **Section of Broached Hole**

FIG. 1.—Broaching a Square Hole

In broaching square holes from the round, or in other cases where there is a decided change of shape, the first teeth take the widest cut as at *A*, Fig. 1. This evens up the work of the different teeth as to the length of surface cut as the hole approaches a square as seen at *B*.

The blank for the cutting part of each broach is first turned taper by an amount equal to the total cut of the teeth. The tooth spaces are cut about $\frac{1}{2}$ inch apart and about $\frac{3}{32}$ inch deep; this depends on the diameter of the broach, since it must not be unduly weakened. It is then milled $\frac{15}{16}$ inch square as shown. The longer the hole, the more chip room must be provided.

Where the hole or other surface to be broached is short, the teeth are often cut on an angle to give a shearing cut. This is also done to prevent chatter at times, another remedy being to space the teeth unevenly, as with reamers.

Broaches are made both solid and in sections, the latter to permit the renewal of teeth that have become worn or broken. High speed steel is common, and carbide-tipped broaches are being used. Both 18–4–1 and 18–4–2 and molybdenum steels are also used. The spacing of the teeth, the undercut, or rake, of the teeth, and the speed vary widely with the material and the surfaces being cut. These sectional broaches are made in a variety of ways, Fig. 2 showing examples where the sections are practically discs held on a central arbor. In some cases, several teeth are made on one section. This is for broaching internal gears having 66 teeth, 20 diametral pitch, and $\frac{1}{2}$-inch face. Each tooth cuts 0.006, and the last three teeth are straight to ensure the size being accurate.

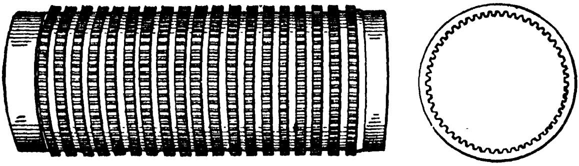


FIG. 2.—Broach for Internal Gears

The Connecticut Broach and Machine Company suggests the following spacing for teeth on work of different lengths. Teeth are spaced more closely for round broaches than in spline broaches because the cut per tooth is about one-half that for splines.

TOOTH SPACING, IN INCHES	LENGTH OF WORK, IN INCHES
$\frac{1}{4}$	$\frac{1}{4}$ to $\frac{1}{2}$
$\frac{5}{16}$	$\frac{9}{16}$ to $\frac{15}{16}$
$\frac{3}{8}$	1 to $1\frac{3}{8}$
$\frac{7}{16}$	$1\frac{7}{16}$ to $1\frac{5}{8}$
$\frac{1}{2}$	$1\frac{11}{16}$ to 2
$\frac{9}{16}$	$2\frac{1}{16}$ to $2\frac{1}{2}$
$\frac{5}{8}$	$2\frac{9}{16}$ to 3
$\frac{11}{16}$	$3\frac{1}{16}$ to $3\frac{1}{2}$
$\frac{3}{4}$	$3\frac{5}{8}$ to $4\frac{1}{4}$
$\frac{13}{16}$	$4\frac{5}{16}$ to $4\frac{3}{4}$
$\frac{7}{8}$	$4\frac{13}{16}$ to $5\frac{1}{2}$

Undercut, or rake, varies 10 to 12 degrees with about 2 degrees for clearance. Broaching speed varies from 15 to 30 feet per minute. Soluble oils mixed with water are commonly used. For tool steel and tough forgings, a heavy compound and 4 per cent sulphur are used. For cold-rolled steel and similar material, this would be considerably diluted.

BROACHING ROUND HOLES

Round holes have been broached instead of reamed in some places for many years, and the practice is growing. It was formerly confined to soft metal, such as shaft bearings, but is now being made to cover all the metals, in some few cases broaching from a cored hole. For small work, a small arbor press with a sort of sub-press can be used to advantage. For larger work the arbor press operated by power is very good, and, of course, the regular broaching machine can be used in any case. These are for "push" broaching.

Two broaches used in one shop are shown in Fig. 3; other sizes can be made in proportion. These were used in a hand arbor press. The first 5 or 6 teeth do most of the cutting, as these broaches only finish the holes instead of reaming. In some cases with broaches for soft-metal bearings and even in cast iron, the large end was left plain or with buttons and a trifling amount larger than the last tooth. It then acted as a burnisher and compresses the metal. This required a large amount of power.

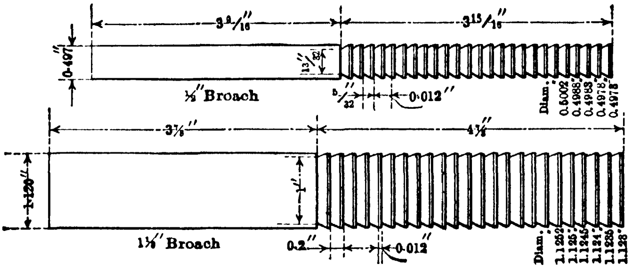


FIG. 3.—Push Broaches for Round Holes

In broaching round holes in cast iron, the broach was made from 0.0002 to 0.0003 inch larger than the nominal size, and the land was 0.012, as shown. The holes were drilled close to size so as to leave very little work for the broach. In this case about 0.002 inch was left for broaching.

Push broaches are usually short, being from 6 to 12 inches long.

TO SAVE TIME IN BROACHING OUT SQUARE HOLES

The fit on a square shaft depends almost entirely on the flat surfaces at or near the corners. With this in mind, it is an economy to bore or drill the round hole in the gear slightly larger than the diameter across the flats of the squared shaft, as shown in Fig. 4.

Taking a 1¼-inch square shaft and boring the hole $\frac{1}{16}$ inch larger, or 1$\frac{5}{16}$ inches in diameter, we see in the illustration exactly what this would mean. The amount of metal to be cut out would be materially reduced, the portion *AB* not being touched by the broach in any way. Yet the remaining surface in the corners would be ample to carry all the load, and the clearance *AB* would allow the best of lubrication.

The center relief, as shown, gives considerable added chip space as well as reduces the amount of chip, thus allowing a heavier chip per tooth. This may either reduce the length of the broach or allow a longer hole, such as two holes at once, to be broached with the same length of broach.

The round-cornered square holes are used for square-form shafts when sliding gears or other similar parts are placed thereon, eliminating the use of keys.

The automobile created and originated a large demand for square shafts, and they are now used extensively in commercial work since the difficulty of producing square holes at a minimum cost has been overcome.

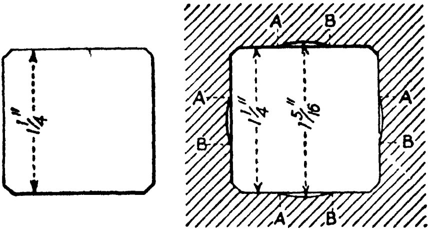


FIG. 4.—Center Relief for Square Holes

The following table gives the standard dimensions of round-cornered square holes, established by The J. N. La Pointe Company.

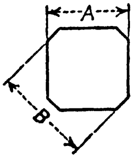


TABLE OF STANDARD DIMENSIONS OF ROUND-CORNERED SQUARE HOLES

No. of Square	Size of Square, in Inches	Size of Shaft, in Inches	No. of Square	Size of Square, in Inches	Size of Shaft, in Inches
	A	*B*		*A*	*B*
1	1	$1\frac{1}{4}$	10	$1\frac{9}{16}$	$1\frac{15}{16}$
2	$1\frac{1}{16}$	$1\frac{5}{16}$	11	$1\frac{5}{8}$	2
3	$1\frac{1}{8}$	$1\frac{3}{8}$	12	$1\frac{11}{16}$	$2\frac{1}{8}$
4	$1\frac{3}{16}$	$1\frac{1}{2}$	13	$1\frac{3}{4}$	$2\frac{1}{4}$
5	$1\frac{1}{4}$	$1\frac{9}{16}$	14	$1\frac{13}{16}$	$2\frac{5}{16}$
6	$1\frac{5}{16}$	$1\frac{5}{8}$	15	$1\frac{7}{8}$	$2\frac{3}{8}$
7	$1\frac{3}{8}$	$1\frac{3}{4}$	16	$1\frac{15}{16}$	$1\frac{7}{16}$
8	$1\frac{7}{16}$	$1\frac{13}{16}$	17	2	$2\frac{1}{2}$

BROACHING MACHINES

Broaching machines now include a number of types, such as horizontal, vertical, and rotary. Some use a screw, and others hydraulic mechanisms, for pulling the broach. Multiple machines are also in use. The rotary machines of the American type hold the work on a rotating table which carries it between stationary broaches fixed around the outside. These are loaded and unloaded while the table is in motion and give practically continuous cutting.

Another type of broaching machine, the National, revolves round work, such as shafts with gears forged on the end, against a slowly rotating broach. This broach divides the work between its many teeth, the last tooth reducing the shaft to its correct diameter. The complete rotation of the cutter brings the first, or low, tooth in position for work on the next shaft.

Push broaching machines are practically arbor presses. They are operated either by a screw or hydraulically.

BROACHING SPEEDS

Broaching speed varies greatly with the material and the type of broach and machine used. Some tractor plants run from 12 to 15 feet per minute because they prefer to take a heavy cut per tooth and so reduce the length of the broach used, which reduces tool cost. The average broaching speed is perhaps 20 feet per minute, with 30 feet the practice in some cases.

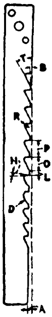


FIG. 5

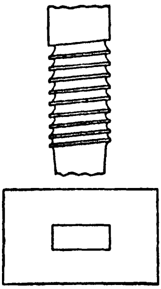


FIG. 6

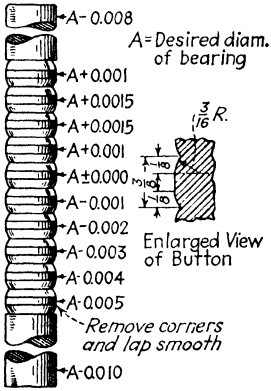


FIG. 7

FIG. 5.—Details of Broach Teeth
FIG. 6.—Angular Teeth for Square Holes
FIG. 7.—Burnishing for Broached Holes

TEETH FOR BROACHES

Usual tooth shapes are shown in Fig. 5. Tooth spacing or pitch is 0.35*C*, where *C* is the length of the cut. With a cutting length under ½ inch, use 0.20*C* to get two teeth in the cut.

Land *L* is ⅙*P*, backed off about ¼ degree. Tooth angle *T* can usually be 30 degrees. The fillet at the bottom of the tooth should be as large as possible. Chip clearance may sometimes be increased by curving, as at *D*. A rake angle of 5 to 7 degrees, as *H*, is usual. Broaches start better if the first three or four teeth are closer than the regular pitch.

SQUARE BROACHES

Broaches for square or rectangular holes will cut more easily if the teeth are at an angle as in Fig. 6. Teeth on opposite sides should have the angle in reverse to avoid side thrust.

BURNISHING BARS

Bearings and bushings are frequently burnished after broaching by a bar with polished buttons, as in Fig. 7. This has 10 buttons which increase the diameter by a total of only 0.001 inch. The lower or entering end is 0.010 inch below size, the button diameters increasing by 0.001 inch until 0.001 inch oversize is reached. The eighth and ninth buttons are 0.0015 inch oversize, whereas the last is 0.001 inch and the upper end has a clearance of 0.002 inch. The diameter of the final button ensures a bearing clearance of 0.001 inch, even though the metal may close in after the 0.0015-inch buttons pass. Burnishing buttons are sometimes included in the broach following the cutting teeth.

SECTION XV

BOLTS, NUTS, AND SCREWS

Standard Bolts and Nuts

Bolts, nuts, and screws are all being changed to conform to practical standards and to reduce odd wrench sizes wherever advisable. The following pages show the sizes recommended and in some cases retain the old tables. It will be noted that tolerances are now given for boltheads as well as for the threads.

AREAS OF STANDARD BOLTS FROM ¼ TO 3 INCHES IN DIAMETER

Bolt		Areas	
Diameter of Bolt	No. of Threads per Inch	Full Bolt	Bottom of Thread
¼	20	0.049	0.027
5/16	18	0.077	0.045
⅜	16	0.110	0.068
7/16	14	0.150	0.093
½	13	0.196	0.126
9/16	12	0.248	0.162
⅝	11	0.307	0.202
¾	10	0.442	0.302
⅞	9	0.601	0.419
1	8	0.785	0.551
1⅛	7	0.994	0.693
1¼	7	1.227	0.890
1⅜	6	1.485	1.054
1½	6	1.767	1.294
1⅝	5½	2.074	1.515
1¾	5	2.405	1.745
1⅞	5	2.761	2.049
2	4½	3.142	2.300
2¼	4½	3.976	3.021
2½	4	4.909	3.716
2¾	4	5.940	4.620
3	3½	7.069	5.428

Bolts are now made of so many kinds of steel and other materials that bolt manufacturers no longer list tensile strengths owing to the wide variations in the quality of the materials used. As the old table, which gave values of 12,000 and 17,500 pounds tensile strength, now applies to but few materials, it seems best to omit all but the cross-section areas both of the full bolt and at the bottom of the thread. Although this necessitates the calculation of safe bolt strength for each material, it is now considered better practice.

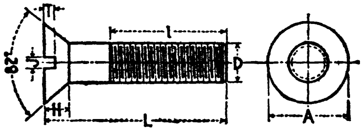
SLOTTED-HEAD MACHINE SCREWS, CAPSCREWS, AND WOOD SCREWS

These heads are standard for machine screws and capscrews. All, except the fillister head, are also standard for wood screws. In capscrews the round head is also called "button" head. In wood screws the oval head is sometimes called "French" head.

Flat Round Oval Fillister

Head proportions are given in Tables 1 to 15.

The dimensions given in the tables are A.S.A. standards and have been adopted by the American Screw Company, which also furnished the dimensions of the Phillips cross-slot head, as shown in Tables 9 to 15. Standard wood screws are shown in Tables 38 to 42. Cross-slotted screws have also been made by Reed & Prince.



Formulas

Head diameter: Maximum $A = 2.040D - 0.003$, Minimum $A = 1.960D - 0.013$.
Height of head: Maximum $H = 0.619D - 0.002$, Minimum $H = 0.552D - 0.007$.
NOTE.—Width of slot: Maximum $J = 0.182D + 0.020$; Minimum $J = 0.164D + 0.010$.
It is the same in all types of machine screws.
Depth of slot: Maximum $T = 0.288D - 0.002$; Minimum $T = 0.192D - 0.002$.
Countersink angle; maximum, 82 degrees; minimum, 80 degrees.

TABLE 1.—HEAD DIMENSIONS, FLAT HEAD SCREWS

Nominal Size	Threads per Inch	*D*	*A*		*H*		*J*		*T*	
		Maximum Diameter	Head Diameter		Height of Head		Width of Slot		Depth of Slot	
			Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
2	2–56	0.086	0.172	0.156	0.051	0.040	0.036	0.024	0.023	0.015
3	3–48	0.099	0.199	0.181	0.059	0.048	0.038	0.026	0.027	0.017
4	4–40	0.112	0.225	0.207	0.067	0.055	0.040	0.028	0.030	0.020
5	5–40	0.125	0.252	0.232	0.075	0.062	0.043	0.031	0.034	0.022
6	6–32	0.138	0.279	0.257	0.083	0.069	0.045	0.033	0.038	0.024
8	8–32	0.164	0.332	0.308	0.100	0.084	0.050	0.037	0.045	0.029
10	10–24–32	0.190	0.385	0.359	0.116	0.098	0.055	0.041	0.053	0.034
12	12–24	0.216	0.438	0.410	0.132	0.112	0.059	0.045	0.060	0.039
$\frac{1}{4}$	$\frac{1}{4}$–20	0.250	0.507	0.477	0.153	0.131	0.066	0.051	0.070	0.046
$\frac{5}{16}$	$\frac{5}{16}$–18	0.3125	0.636	0.600	0.192	0.166	0.077	0.061	0.088	0.058
$\frac{3}{8}$	$\frac{3}{8}$–16	0.375	0.762	0.722	0.230	0.200	0.088	0.072	0.106	0.070
$\frac{7}{16}$	$\frac{7}{16}$–14	0.4375	0.890	0.845	0.269	0.235	0.099	0.083	0.108	0.070
$\frac{1}{2}$	$\frac{1}{2}$–13	0.500	1.017	0.967	0.307	0.269	0.110	0.094	0.110	0.070

All dimensions in inches.

NOTE:—The unthreaded body diameter of machine screws will have approximately the same tolerances as the pitch diameter of the threads shown in the American National Standard for screw threads, Class 2 Free Fit, where the number of threads per inch are the same.

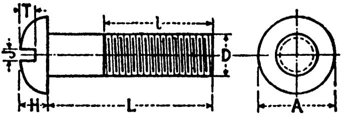


TABLE 2.—HEAD DIMENSIONS, ROUND HEAD SCREWS

Nominal Size	D	A		H		J		T	
	Maximum Diameter	Head Diameter		Height of Head		Width of Slot		Depth of Slot	
		Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
2	0.086	0.162	0.146	0.070	0.059	0.036	0.024	0.048	0.036
3	0.099	0.187	0.169	0.078	0.067	0.038	0.026	0.053	0.040
4	0.112	0.211	0.193	0.086	0.075	0.040	0.028	0.058	0.043
5	0.125	0.236	0.217	0.095	0.083	0.043	0.031	0.062	0.047
6	0.138	0.260	0.240	0.103	0.091	0.045	0.033	0.067	0.050
8	0.164	0.309	0.287	0.119	0.107	0.050	0.037	0.076	0.057
10	0.190	0.359	0.334	0.136	0.124	0.055	0.041	0.086	0.064
12	0.216	0.408	0.382	0.152	0.140	0.059	0.045	0.095	0.071
$\frac{1}{4}$	0.250	0.472	0.443	0.174	0.161	0.066	0.051	0.108	0.080
$\frac{5}{16}$	0.3125	0.591	0.557	0.214	0.200	0.077	0.061	0.130	0.097
$\frac{3}{8}$	0.375	0.708	0.670	0.254	0.239	0.088	0.072	0.153	0.114
$\frac{7}{16}$	0.4375	0.825	0.783	0.293	0.278	0.099	0.083	0.186	0.146
$\frac{1}{2}$	0.500	0.944	0.897	0.333	0.317	0.110	0.094	0.219	0.179

All dimensions in inches.

Formulas

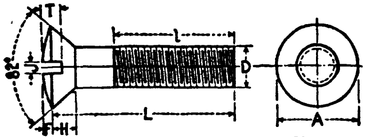
Head diameter: Maximum $A = 1.887D$; Minimum $A = 1.813D - 0.010$.

Height of head: Maximum $H = 0.636D + 0.015$; Minimum $H = 0.624D + 0.005$.

Depth of slot: Maximum $T = 0.362D + 0.017$; Minimum $T = 0.268D + 0.013$.

Shape of head: semielliptical.

For threads per inch see Table 1.



Formulas

Head diameter and height of head are same as in Table 1.
Width of slot is same in all types of machine screws.
Depth of slot: Maximum $T = 0.556D - 0.003$; Minimum $T = 0.460D - 0.003$.
Height of oval: Maximum $F = 0.304D + 0.003$; Minimum $F = 0.268D - 0.001$.
Total height of head: Maximum $(F + H)$ = Maximum F + Maximum $H = 0.923D + 0.001$; Minimum $(F + H)$ = Minimum F + Minimum $H = 0.820D - 0.008$.
Countersink angle; maximum, 82 degrees; minimum, 80 degrees.
For threads per inch see Table 1.

TABLE 3.—HEAD DIMENSIONS, OVAL HEAD SCREWS

	D	A		H		J		T		F		$F + H$	
Nominal Size	Maximum Diameter	Head Diameter		Height of Head		Width of Slot		Depth of Slot		Height of Oval		Total Height of Head	
		Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
2	0.086	0.172	0.156	0.051	0.040	0.036	0.024	0.045	0.037	0.029	0.022	0.080	0.063
3	0.099	0.199	0.181	0.059	0.048	0.038	0.026	0.052	0.043	0.033	0.026	0.092	0.073
4	0.112	0.225	0.207	0.067	0.055	0.040	0.028	0.059	0.049	0.037	0.029	0.104	0.084
5	0.125	0.252	0.232	0.075	0.062	0.043	0.031	0.067	0.055	0.041	0.033	0.116	0.095
6	0.138	0.279	0.257	0.083	0.069	0.045	0.033	0.074	0.060	0.045	0.036	0.128	0.105
8	0.164	0.332	0.308	0.100	0.084	0.050	0.037	0.088	0.072	0.053	0.043	0.152	0.126
10	0.190	0.385	0.359	0.116	0.098	0.055	0.041	0.103	0.084	0.061	0.050	0.176	0.148
12	0.216	0.438	0.410	0.132	0.112	0.059	0.045	0.117	0.096	0.069	0.057	0.200	0.169
$\frac{1}{4}$	0.250	0.507	0.477	0.153	0.132	0.066	0.051	0.136	0.112	0.079	0.066	0.232	0.197
$\frac{5}{16}$	0.3125	0.636	0.600	0.192	0.166	0.077	0.061	0.171	0.141	0.098	0.083	0.290	0.249
$\frac{3}{8}$	0.375	0.762	0.722	0.230	0.200	0.088	0.072	0.206	0.170	0.117	0.100	0.347	0.300
$\frac{7}{16}$	0.4375	0.890	0.845	0.269	0.235	0.099	0.083	0.240	0.200	0.138	0.120	0.405	0.350
$\frac{1}{2}$	0.5000	1.017	0.967	0.307	0.269	0.110	0.094	0.275	0.230	0.150	0.132	0.462	0.402

All dimensions in inches.

TABLE 4.—HEAD DIMENSIONS—TRUSS-HEAD MACHINE SCREWS

Size	Head Diameter, in Inches *A*	Head Height, in Inches *H*	Slot Width, in Inches *D*	Slot Depth, in Inches *E*
4	0.262	0.076	0.040	0.045
	0.242	0.056	0.028	0.043
5	0.291	0.082	0.043	0.049
	0.271	0.062	0.031	0.047
6	0.326	0.092	0.045	0.052
	0.306	0.072	0.033	0.050
8	0.385	0.108	0.050	0.059
	0.365	0.088	0.037	0.057
10	0.448	0.124	0.055	0.066
	0.428	0.104	0.041	0.064
12	0.510	0.140	0.059	0.073
	0.490	0.120	0.045	0.071
$\frac{1}{4}$	0.573	0.155	0.066	0.083
	0.553	0.135	0.051	0.081
$\frac{5}{16}$	0.698	0.186	0.077	0.099
	0.678	0.166	0.061	0.097
$\frac{3}{8}$	0.823	0.218	0.088	0.116
	0.803	0.198	0.072	0.114

American Screw Company.

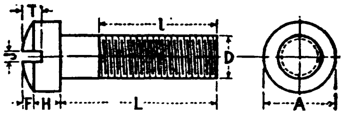


TABLE 5.—HEAD DIMENSIONS, FILLISTER HEAD MACHINE SCREWS

Nominal Size	D	A		H		J		T		F		F + H	
	Maximum Diameter	Head Diameter		Height of Head		Width of Slot		Depth of Slot		Height of Oval		Total Height of Head	
		Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
2	0.086	0.140	0.124	0.055	0.045	0.036	0.024	0.037	0.021	0.028	0.018	0.083	0.063
3	0.099	0.161	0.145	0.063	0.052	0.038	0.026	0.043	0.026	0.032	0.021	0.095	0.073
4	0.112	0.183	0.166	0.072	0.060	0.040	0.028	0.048	0.031	0.035	0.024	0.107	0.084
5	0.125	0.205	0.187	0.081	0.068	0.043	0.031	0.054	0.036	0.039	0.027	0.120	0.095
6	0.138	0.226	0.208	0.089	0.076	0.045	0.033	0.060	0.041	0.043	0.029	0.132	0.105
8	0.164	0.270	0.250	0.106	0.091	0.050	0.037	0.071	0.050	0.050	0.035	0.156	0.126
10	0.190	0.313	0.292	0.123	0.107	0.055	0.041	0.083	0.060	0.057	0.041	0.180	0.148
12	0.216	0.357	0.334	0.141	0.123	0.059	0.045	0.094	0.070	0.064	0.047	0.205	0.169
$\frac{1}{4}$	0.250	0.414	0.389	0.163	0.143	0.066	0.051	0.109	0.083	0.074	0.054	0.237	0.197
$\frac{5}{16}$	0.3125	0.519	0.490	0.205	0.181	0.077	0.061	0.137	0.106	0.092	0.068	0.297	0.249
$\frac{3}{8}$	0.375	0.622	0.590	0.246	0.218	0.088	0.072	0.164	0.129	0.109	0.082	0.355	0.300

All dimensions in inches.

Formulas

Head diameter: Maximum A = 1.670 D − 0.004, Minimum A = 1.610 D − 0.014.

Height of head (side): Maximum H = 0.660 D − 0.002, Minimum H = 0.600 D − 0.007.

Width of slot is same in all types of machine screws.

Depth of slot: Maximum T = 0.440 D − 0.001, minimum T = 0.374 D − 0.011.

Total height of head: Maximum (F + H) = Maximum F + Maximum H, Minimum (F + H) = Minimum F + Minimum H.

Height of oval: Maximum F = 0.280 D + 0.004, Minimum F = 0.220 D − 0.001.

For threads per inch see Table 1.

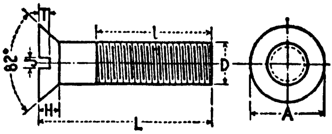


TABLE 6.—HEAD DIMENSIONS, FLAT HEAD CAP SCREWS

Nominal Size	D	A		H	J		T	
	Maximum Diameter	Head Diameter		Height of Head	Width of Slot		Depth of Slot	
		Maximum	Minimum	Nominal	Maximum	Minimum	Maximum	Minimum
1/4	0.250	1/2	0.477	0.146	0.070	0.058	0.073	0.053
5/16	0.3125	5/8	0.598	0.183	0.079	0.065	0.091	0.066
3/8	0.375	3/4	0.719	0.220	0.088	0.074	0.110	0.080
7/16	0.4375	13/16	0.780	0.220	0.098	0.083	0.110	0.075
1/2	0.500	7/8	0.841	0.220	0.110	0.094	0.110	0.070
9/16	0.5625	1	0.962	0.256	0.123	0.106	0.128	0.083
5/8	0.625	1 1/8	1.083	0.293	0.138	0.119	0.146	0.096
3/4	0.750	1 3/8	1.326	0.366	0.154	0.134	0.183	0.123

All dimensions in inches.

NOTE 1: The unthreaded body diameter of cap screws will have the same tolerances as the major thread diameter shown in the American National Standard for screw heads, Class 2 free fit, where the number of threads per inch is the same.

Formulas

Head diameter: Maximum A = nominal (no formula), Minimum A = Maximum A − (0.03 Max. A + 0.008).

Height of head: Nominal H = computed from maximum D and maximum A, with 81-degree (mean) angle. Nominal H, subject to variations in A and D and angle.

Width of slot: Nominal J = 0.160 D + 0.024 = S (approximately cutter width), Maximum J = S + (0.05 S + 0.003), Minimum J = S − (0.05 S + 0.003).

Depth of slot: Maximum T = 0.500 H Nominal, Minimum T = Maximum T − 0.08 D.

Countersink angle: maximum 82 degrees, minimum 80 degrees.

Screw Points

The points of all cap screws shall be flat, the flat being normal to the axis of the screw, and shall be chamfered at an angle of 35 degrees with the surface of the flat, plus 5 degrees, minus 0 degree; the chamfer to extend to the bottom of the thread. The edge of the chamfer is to be slightly rounded.

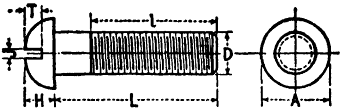


TABLE 7.—HEAD DIMENSIONS, BUTTON HEAD CAP SCREWS

Nominal Size	D	A		H		J		T	
	Maximum Diameter	Head Diameter		Height of Head		Width of Slot		Depth of Slot	
		Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
$\frac{1}{4}$	0.250	$\frac{7}{16}$	0.418	0.191	0.175	0.070	0.058	0.117	0.097
$\frac{5}{16}$	0.3125	$\frac{9}{16}$	0.541	0.246	0.226	0.079	0.065	0.151	0.126
$\frac{3}{8}$	0.375	$\frac{5}{8}$	0.602	0.273	0.251	0.088	0.074	0.167	0.137
$\frac{7}{16}$	0.4375	$\frac{3}{4}$	0.725	0.328	0.302	0.098	0.083	0.202	0.167
$\frac{1}{2}$	0.500	$\frac{13}{16}$	0.786	0.355	0.328	0.110	0.094	0.219	0.179
$\frac{9}{16}$	0.5625	$\frac{15}{16}$	0.908	0.410	0.379	0.123	0.106	0.253	0.208
$\frac{5}{8}$	0.625	1	0.970	0.438	0.405	0.138	0.119	0.270	0.220
$\frac{3}{4}$	0.750	$1\frac{1}{4}$	1.215	0.547	0.506	0.154	0.134	0.337	0.277

All dimensions in inches.

Formulas

Head diameter: maximum A = nominal (no formula); minimum A = maximum A − (0.02 maximum A + 0.010).

Height of head; maximum $H = \frac{7}{16}$ maximum A; minimum H = maximum H − (0.03 maximum A + 0.003).

Width of slot is same as in Table 6.

Depth of slot: maximum $T = \frac{2}{3}$ minimum H; minimum T = maximum $T - 0.08D$.

Shape of head: semielliptical.

Cap-Screw Lengths

The length shall be measured from the largest diameter of the bearing surface of the head to the extreme point, on a line parallel to the axis of the screw.

The difference between consecutive lengths of screws:

For screw lengths ¼ to 1 inch shall be ⅛ inch.
For screw lengths 1 to 4 inches shall be ¼ inch.
For screw lengths 4 to 6 inches shall be ½ inch.

The tolerance in screw length shall be 3 per cent of the nominal length, with a minimum tolerance of 0.030 inch; one-third of the tolerance to be applied minus, and two-thirds plus.

Thread Lengths

Slotted-head cap screws shall be regularly threaded coarse pitch, and when so threaded shall have a length of thread equal to $2D + \frac{1}{4}$ inch. Screws too short to allow the formula length of thread may be threaded as close to the head as practicable.

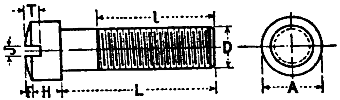


TABLE 8.—HEAD DIMENSIONS, FILLISTER HEAD CAP SCREWS

	D	A		H		J		T		F		F + H	
Nominal Size	Maximum Diameter	Head Diameter		Height of Head		Width of Slot		Depth of Slot		Height of Oval		Total Height of Head	
		Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
1/4	0.250	3/8	0.363	11/64	0.157	0.070	0.058	0.097	0.077	0.044	0.038	0.216	0.195
5/16	0.3125	7/16	0.424	13/64	0.186	0.079	0.065	0.115	0.090	0.050	0.044	0.253	0.230
3/8	0.375	9/16	0.547	1/4	0.229	0.088	0.074	0.142	0.112	0.064	0.056	0.314	0.285
7/16	0.4375	5/8	0.608	19/64	0.274	0.098	0.083	0.168	0.133	0.071	0.063	0.368	0.337
1/2	0.500	3/4	0.731	21/64	0.301	0.110	0.094	0.188	0.148	0.084	0.075	0.412	0.376
9/16	0.5625	13/16	0.792	3/8	0.347	0.123	0.106	0.214	0.169	0.091	0.081	0.466	0.428
5/8	0.625	7/8	0.853	27/64	0.392	0.138	0.119	0.240	0.190	0.099	0.088	0.521	0.480
3/4	0.750	1	0.976	1/2	0.466	0.154	0.134	0.283	0.233	0.112	0.100	0.612	0.566
7/8	0.875	1 1/8	1.098	19/32	0.556	0.173	0.151	0.334	0.264	0.126	0.113	0.720	0.669
1	1.000	1 5/16	1.282	21/32	0.613	0.194	0.170	0.372	0.292	0.146	0.131	0.802	0.744

All dimensions in inches.

Formulas

Head diameter: Maximum A = nominal (no formula), Minimum A = Maximum A − (0.02 Maximum A + 0.004).
Height of head (side): Maximum H = ⅔ D to nearest 64th inch, Minimum H = Maximum H − (0.03 Max. A + 0.004).
Width of slot is same as in Tables 6 and 7.
Depth of slot: Maximum T = 0.50 (Minimum F + Minimum H), Minimum T = Maximum T − 0.08 D.
Height of oval: Maximum F = 0.110 Maximum A + 0.002, Minimum F = 0.100 Maximum A.
Total height of head: Maximum (F + H) = Maximum F + Maximum H, Minimum (F + H) = Minimum F + Minimum H.

Formulas for F included for purpose of determining tolerances for T and F and are not to be used for inspection purposes.

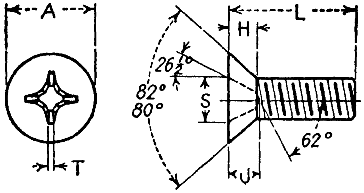


TABLE 9.—HEAD DIMENSIONS—FLAT-HEAD MACHINE SCREWS AMERICAN PHILLIPS

Size	Head Diameter, in Inches *A*	Head Height, in Inches *H*	Recess Spread, in Inches *S*	Recess Depth, in Inches *J*	Wing Thickness, in Inches *T*
2	0.172	0.051	0.105	0.066	0.020
	0.156	0.040	0.095	0.056	0.016
3	0.199	0.059	0.117	0.078	0.020
	0.181	0.048	0.107	0.068	0.016
4	0.225	0.067	0.130	0.091	0.020
	0.207	0.055	0.120	0.081	0.016
5	0.232	0.075	0.151	0.083	0.027
	0.252	0.062	0.141	0.073	0.023
6	0.279	0.083	0.166	0.098	0.027
	0.257	0.069	0.156	0.088	0.023
8	0.332	0.100	0.181	0.113	0.027
	0.308	0.084	0.171	0.103	0.023
10	0.385	0.116	0.196	0.128	0.027
	0.359	0.098	0.186	0.118	0.023
12	0.438	0.132	0.260	0.148	0.032
	0.410	0.112	0.250	0.138	0.028
¼	0.507	0.153	0.275	0.163	0.032
	0.477	0.131	0.265	0.153	0.028
5/16	0.636	0.192	0.357	0.208	0.045
	0.600	0.166	0.347	0.198	0.041
⅜	0.762	0.230	0.385	0.237	0.045
	0.722	0.200	0.375	0.227	0.041
7/16	0.890	0.269	0.401	0.253	0.045
	0.845	0.235	0.391	0.243	0.041
½	1.017	0.307	0.416	0.268	0.045
	0.967	0.269	0.406	0.258	0.041

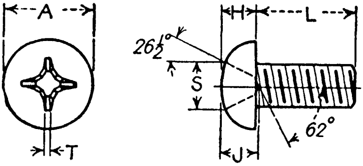


TABLE 10.—HEAD DIMENSIONS—ROUND-HEAD MACHINE SCREWS AMERICAN PHILLIPS

Size	Head Diameter, in Inches *A*	Head Height, in Inches *H*	Recess Spread, in Inches *S*	Recess Depth, in Inches *J*	Wing Thickness, in Inches *T*
2	0.162	0.070	0.111	0.089	0.020
	0.146	0.059	0.101	0.079	0.016
3	0.187	0.078	0.119	0.097	0.020
	0.169	0.067	0.109	0.087	0.016
4	0.211	0.086	0.127	0.105	0.020
	0.193	0.075	0.117	0.095	0.016
5	0.236	0.095	0.151	0.104	0.027
	0.217	0.083	0.141	0.094	0.023
6	0.260	0.103	0.159	0.112	0.027
	0.240	0.091	0.149	0.102	0.023
8	0.309	0.119	0.175	0.128	0.027
	0.287	0.107	0.165	0.118	0.023
10	0.359	0.136	0.192	0.145	0.027
	0.334	0.124	0.182	0.135	0.023
12	0.408	0.152	0.246	0.165	0.032
	0.382	0.140	0.236	0.155	0.028
¼	0.472	0.174	0.265	0.187	0.032
	0.443	0.161	0.255	0.177	0.028
$\frac{5}{16}$	0.591	0.214	0.305	0.227	0.032
	0.557	0.200	0.295	0.217	0.028
⅜	0.708	0.254	0.384	0.281	0.045
	0.670	0.239	0.374	0.271	0.041
$\frac{7}{16}$	0.825	0.293	0.398	0.297	0.045
	0.783	0.278	0.388	0.287	0.041
½	0.944	0.333	0.413	0.314	0.045
	0.897	0.317	0.403	0.304	0.041

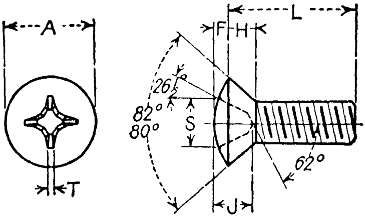


Table 11.—Head Dimensions—Oval-Head Machine Screws American Phillips

Size	Head Diameter, in Inches *A*	Head Height, in Inches *H*	Height of Oval, in Inches *F*	Total Height of Head, in Inches *F + H*	Recess Spread, in Inches *S*	Recess Depth, in Inches *J*	Wing Thickness, in Inches *T*
2	0.172	0.051	0.029	0 080	0.109	0.078	0.020
	0.156	0.040	0.022	0.062	0.099	0.067	0.016
3	0.199	0.059	0 033	0 092	0.121	0.090	0 020
	0.181	0.048	0 026	0 074	0.111	0.080	0 016
4	0.225	0.067	0.037	0 104	0 133	0.103	0 020
	0.207	0.055	0.029	0.084	0 123	0.093	0 016
5	0 232	0.075	0 041	0.116	0 155	0.098	0 027
	0.252	0.062	0 033	0.095	0.145	0.088	0.023
6	0.279	0.083	0 045	0.128	0 170	0.114	0.027
	0.257	0.069	0.036	0 105	0.160	0 104	0.023
8	0.332	0 100	0.053	0.153	0.189	0.133	0.027
	0.308	0.084	0.043	0 127	0 179	0.123	0 023
10	0.385	0.116	0.061	0.177	0 206	0.151	0 027
	0.359	0.098	0.050	0 148	0.196	0.141	0.023
12	0.438	0.132	0.069	0 201	0 267	0 174	0.032
	0.410	0.112	0.057	0 169	0.257	0.164	0.028
¼	0.507	0.153	0.079	0.232	0.287	0.194	0.032
	0.477	0.131	0.066	0.197	0 277	0.184	0.028
5/16	0.636	0.192	0.098	0.290	0 387	0 266	0.045
	0.600	0.166	0.083	0 249	0 377	0 256	0.041
⅜	0.762	0.230	0.117	0.347	0.407	0 285	0.045
	0.722	0.200	0.100	0 300	0.397	0.275	0.041
7/16	0.890	0.269	0.138	0.407	0.419	0.298	0.045
	0.845	0.235	0.120	0.355	0.409	0.288	0.041
½	1.017	0.307	0.150	0.407	0 434	0.314	0 045
	0.967	0.269	0.132	0.401	0.424	0.304	0.041

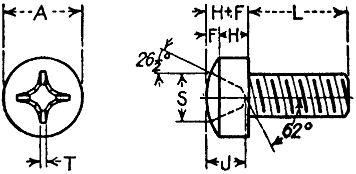


TABLE 12.—HEAD DIMENSIONS—FILLISTER-HEAD MACHINE SCREWS
AMERICAN PHILLIPS

Size	Head Diameter, in Inches *A*	Head Height, in Inches *H*	Height of Oval, in Inches *F*	Total Height of Head, in Inches *F + H*	Recess Spread, in Inches *S*	Recess Depth, in Inches *J*	Wing Thickness, in Inches. *T*
2	0.140	0.055	0.028	0.083	0.103	0.076	0.020
	0.124	0.045	0.018	0.063	0.093	0.066	0.016
3	0.161	0.063	0.032	0.095	0.113	0.087	0.020
	0.145	0.052	0.021	0.073	0.013	0.077	0.016
4	0.183	0.072	0.035	0.107	0.125	0.099	0.020
	0.166	0.062	0.024	0.086	0.115	0.089	0.016
5	0.204	0.081	0.039	0.120	0.158	0.109	0.027
	0.187	0.068	0.027	0.095	0.148	0.099	0.023
6	0.226	0.089	0.043	0.132	0.169	0.121	0.027
	0.208	0.076	0.029	0.105	0.159	0.111	0.023
8	0.270	0.106	0.050	0.156	0.191	0.144	0.027
	0.250	0.091	0.035	0.126	0.181	0.134	0.023
10	0.313	0.123	0.057	0.180	0.213	0.167	0.027
	0.292	0.107	0.041	0.148	0.203	0.157	0.023
12	0.357	0.141	0.064	0.205	0.271	0.191	0.032
	0.334	0.123	0.047	0.169	0.261	0.181	0.028
¼	0.414	0.163	0.074	0.237	0.299	0.220	0.032
	0.389	0.143	0.054	0.197	0.289	0.210	0.028
5/16	0.519	0.205	0.092	0.297	0.352	0.276	0.032
	0.490	0.181	0.068	0.249	0.342	0.266	0.028
⅜	0.622	0.246	0.109	0.355	0.434	0.331	0.045
	0.590	0.218	0.082	0.300	0.424	0.321	0.041
7/16	0.727	0.287	0.126	0.413	0.443	0.334	0.045
	0.690	0.255	0.095	0.350	0.433	0.324	0.041
½	0.831	0.328	0.144	0.472	0.449	0.339	0.045
	0.791	0.293	0.119	0.412	0.439	0.329	0.041

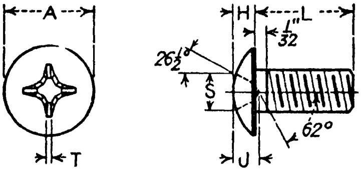


TABLE 13.—HEAD DIMENSIONS—TRUSS-HEAD MACHINE SCREWS AMERICAN PHILLIPS

Size	Head Diameter, in Inches A	Head Height, in Inches H	Recess Spread, in Inches S	Recess Depth, in Inches J	Wing Thickness, in Inches T
4	0.262	0.076	0.109	0.078	0.020
	0.242	0.056	0.109	0.068	0.016
5	0.291	0.082	0.140	0.115	0.020
	0.271	0.062	0.130	0.105	0.016
6	0.326	0.092	0.150	0.120	0.020
	0.306	0.072	0.140	0.110	0.016
8	0.385	0.108	0.170	0.115	0.027
	0.365	0.088	0.160	0.105	0.023
10	0.448	0.124	0.184	0.131	0.027
	0.428	0.104	0.174	0.121	0.023
12	0.510	0.140	0.245	0.155	0.032
	0.490	0.120	0.235	0.145	0.028
¼	0.573	0.155	0.260	0.170	0.032
	0.553	0.135	0.250	0.160	0.028
5/16	0.698	0.186	0.349	0.234	0.045
	0.678	0.166	0.339	0.224	0.041
⅜	0.823	0.218	0.370	0.266	0.045
	0.803	0.198	0.360	0.256	0.041
7/16	0.947	0.249	0.411	0.297	0.045
	0.927	0.229	0.401	0.287	0.041
½	1.072	0.280	0.441	0.328	0.045
	1.052	0.260	0.431	0.318	0.041

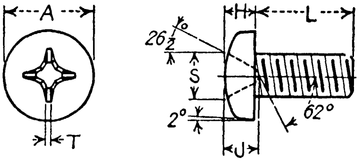


TABLE 14.—HEAD DIMENSIONS—BINDING-HEAD MACHINE SCREWS AMERICAN PHILLIPS

Size	Head Diameter, in Inches A	Head Height, in Inches H	Recess Spread, in Inches S	Recess Depth, in Inches J	Wing Thickness, in Inches T
2	0.176	0.065	0.101	0.071	0.020
	0.164	0.055	0.091	0.061	0.016
3	0.201	0.074	0.108	0.080	0.020
	0.189	0.064	0.098	0.070	0.016
4	0.227	0.083	0.119	0.090	0.020
	0.215	0.073	0.109	0.080	0.016
5	0.205	0.091	0.155	0.103	0.027
	0.238	0.081	0.145	0.093	0.023
6	0.273	0.099	0.163	0.111	0.027
	0.257	0.089	0.153	0.101	0.023
8	0.321	0.115	0.179	0.129	0.027
	0.301	0.105	0.169	0.119	0.023
10	0.374	0.133	0.196	0.147	0.027
	0.354	0.123	0.186	0.137	0.023
12	0.424	0.151	0.256	0.173	0.032
	0.404	0.141	0.246	0.163	0.028
¼	0.484	0.172	0.278	0.192	0.032
	0.464	0.162	0.268	0.182	0.028
5/16	0.625	0.200	0.347	0.227	0.045
	0.605	0.190	0.337	0.217	0.041
⅜	0.748	0.239	0.390	0.266	0.045
	0.728	0.229	0.380	0.256	0.041
7/16	0.873	0.278	0.410	0.288	0.045
	0.853	0.268	0.400	0.278	0.041
½	0.998	0.317	0.424	0.308	0.045
	0.978	0.307	0.414	0.298	0.041

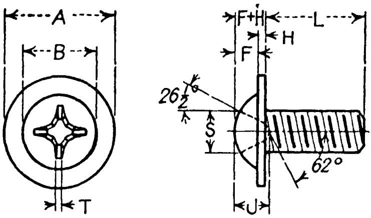
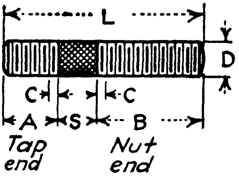


TABLE 15.—HEAD DIMENSIONS—WASHER-HEAD MACHINE SCREWS AMERICAN PHILLIPS

Size	Washer Diameter, in Inches	Diameter of Oval, in Inches	Height of Washer, in Inches	Height of Oval, in Inches	Total Height of Head, in Inches	Recess Spread, in Inches	Recess Depth, in Inches	Wing Thickness, in Inches
	A	*B*	*H*	*F*	*F + H*	*S*	*J*	*T*
2	0.201	0.144	0.018	0.044	0.062	0.092	0.071	0.016
	0.185	0.128	0.012	0.039	0.051	0.102	0.081	0.020
3	0.231	0.165	0.020	0.050	0.070	0.100	0.079	0.016
	0.213	0.147	0.014	0.046	0.060	0.110	0.089	0.020
4	0.261	0.186	0.023	0.057	0.080	0.109	0.088	0.016
	0.243	0.168	0.017	0.051	0.068	0.119	0.098	0.020
5	0.291	0.208	0.025	0.063	0.088	0.132	0.087	0.023
	0.271	0.188	0.019	0.057	0.076	0.142	0.097	0.027
6	0.321	0.228	0.027	0.069	0.096	0.148	0.103	0.023
	0.301	0.208	0.021	0.063	0.084	0.138	0.093	0.027
8	0.370	0.270	0.032	0.081	0.113	0.164	0.119	0.023
	0.358	0.248	0.026	0.075	0.101	0.154	0.109	0.027
10	0.439	0.312	0.036	0.094	0.130	0.170	0.137	0.027
	0.415	0.288	0.030	0.088	0.118	0.180	0.127	0.023
12	0.499	0.354	0.041	0.106	0.147	0.235	0.160	0.032
	0.473	0.338	0.035	0.100	0.135	0.225	0.150	0.028
¼	0.577	0.410	0.048	0.123	0.171	0.251	0.176	0.032
	0.548	0.380	0.040	0.116	0.156	0.241	0.166	0.028
5/16	0.721	0.511	0.060	0.153	0.213	0.295	0.224	0.032
	0.687	0.477	0.051	0.145	0.196	0.285	0.214	0.028
⅜	0.864	0.612	0.071	0.183	0.254	0.351	0.251	0.045
	0.826	0.574	0.061	0.175	0.236	0.341	0.241	0.041
7/16	1.006	0.712	0.082	0.212	0.294	0.369	0.266	0.045
	0.964	0.670	0.072	0.204	0.276	0.359	0.256	0.041
½	1.149	0.814	0.094	0.243	0.337	0.386	0.281	0.045
	1.101	0.766	0.082	0.233	0.315	0.376	0.271	0.041

Tap-End Stud Bolt[1]



DIMENSIONS

D = nominal size or diameter of stud bolt.

L = length of stud bolt over all.

A = length of thread on tap end = $D + \frac{1}{8}$ inch, and is measured from the end of the stud to the end of the imperfect thread.

S = length of unthreaded portion or shoulder = D, except for stud bolts shorter than $4D + \frac{3}{8}$ inch (see following note).

B = length of thread on nut end = $L - (A + S)$ with a minimum of $2D + \frac{1}{4}$ inch and is measured from the end of the stud to the end of the imperfect thread.

Where L is less than $4D + \frac{3}{8}$ inch, which equals $A + S + B$ (minimum), the shoulder length S may be decreased or eliminated entirely in order to retain B at its minimum length of $2D + \frac{1}{4}$ inch.

For very short studs, where the shoulder has been eliminated, B may be decreased below $2D + \frac{1}{4}$ inch, as required, but A should be retained at its full length, $D + \frac{1}{8}$ inch.

Where L is greater than $4D + \frac{3}{8}$ inch, B shall equal $L - (A + S)$, or, in other words, the balance of the stud not consumed by A, the tap-end threading ($A = D + \frac{1}{8}$), and S, the shoulder length ($S = D$).

C = length of imperfect threads and shall not exceed $2\frac{1}{2}$ threads.

"Y"-points shall be chamfered on tap end, and round point on nut end.

THREADS

Nut-end threads shall be American Standard.

Tap-end threads shall be American Standard form with wrench-tight fit.

RECOMMENDED ORDER FOR SPECIFYING DIMENSIONS

To avoid possible misunderstanding when specifying dimensions of tap-end stud bolts, it is recommended that they be given in the following order:

a. For standard tap-end stud bolts—$D \times L$.

b. For special tap-end stud bolts—$D \times L \times A \times B$.

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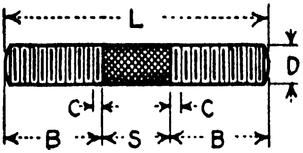
[1] Adopted by American Institute of Bolt, Nut, and Rivet Manufacturers, April, 1935.

Double-End Stud Bolt

(Rod)



DIMENSIONS

D = nominal size or diameter of stud bolt.
L = length of stud bolt over all.
B = length of thread, both ends, $= 2D + \frac{1}{4}$ inch, and is measured from the end of the stud to the end of the imperfect thread.
S = length of unthreaded portion or shoulder $= L - (4D + \frac{1}{2}$ inch) and will vary with the length L.
C = length of imperfect threads and shall not exceed $2\frac{1}{2}$ threads.
"Y"-points on both ends shall be round.

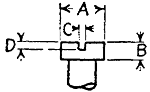
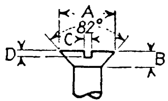
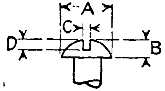
THREADS

The threads on both ends shall be American Standard.

RECOMMENDED ORDER FOR SPECIFYING DIMENSIONS

a. For standard double-end stud bolts—$D \times L$.
b. For special double-end stud bolts—$D \times L \times B$.

TABLE 16.—TAP-DRILL SIZES AND DIMENSIONS OF MACHINE SCREW HEADS
Fine- and Coarse-thread Series Standard

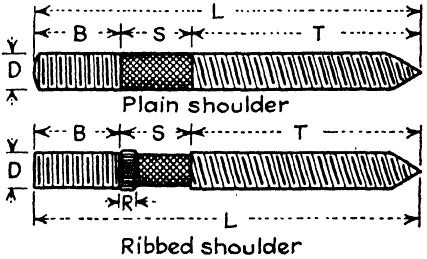
Size of Screw	Threads per Inch	Major Diameter of Screw	Clearance Drill	Tap-Drill Sizes														
				75 to 80 Per Cent of Full Thread	70 to 75 Per Cent of Full Thread	65 to 70 Per Cent of Full Thread												
				Sheet Brass Sheet Nickel Babbitt Dural Fiber White Metal Hard Rubber	Mild Steel Aluminum Cast Iron Cast Brass	Bronze Tool Steel Drop Forging Stainless Steel Cast Steel Nickel Copper	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*
00	96	0.047	55 (0.052)	64 (0.036)	63 (0.037)	63 (0.037)	0.078	0.035	0.010	0.016	0.085	0.022	0.010	0.010				
0	80	0.060	51 (0.067)	56 (0.046)	55 (0.052)	55 (0.052)	0.102	0.046	0.016	0.025	0.115	0.032	0.016	0.016	0.110	0.043	0.016	0.031
1	72	0.073	47 (0.0785)	53 (0.0595)	53 (0.0595)	52 (0.0635)	0.120	0.051	0.020	0.028	0.140	0.038	0.020	0.020	0.132	0.052	0.020	0.035
	64			54 (0.055)	53 (0.0595)	53 (0.0595)												
2	64	0.086	42 (0.0935)	50 (0.070)	49 (0.073)	48 (0.076)	0.137	0.059	0.025	0.031	0.164	0.044	0.025	0.023	0.154	0.060	0.025	0.040
	56			51 (0.067)	50 (0.070)	50 (0.070)												
3	56	0.099	36 (0.1065)	46 (0.081)	45 (0.082)	44 (0.086)	0.158	0.069	0.025	0.035	0.190	0.052	0.025	0.025	0.178	0.069	0.025	0.044
	48			$\frac{5}{64}$	47 (0.0785)	46 (0.081)												
4	48	0.112	31 (0.120)	43 (0.089)	42 (0.0935)	41 (0.096)	0.179	0.078	0.025	0.039	0.216	0.059	0.025	0.027	0.202	0.078	0.025	0.049
	40			44 (0.086)	43 (0.089)	42 (0.0935)												
5	44	0.125	29 (0.136)	38 (0.1015)	37 (0.104)	35 (0.110)	0.200	0.086	0.031	0.043	0.242	0.067	0.031	0.032	0.226	0.087	0.031	0.053
	40			38 (0.1015)	37 (0.104)	36 (0.1065)												
6	40	0.138	26 (0.147)	33 (0.113)	32 (0.116)	31 (0.120)	0.220	0.094	0.031	0.046	0.268	0.074	0.031	0.034	0.250	0.096	0.031	0.058
	32			35 (0.110)	$\frac{7}{64}$	33 (0.113)												

8	36	0.164	17 (0.173)	29 (0.136)	29 (0.136)	28 (0.1405)	0.264	0.110	0.040	0.054	0.320	0.090	0.040	0.040	0.298	0.114	0.040	0.067
	32			29 (0.136)	29 (0.136)	28 (0.1405)												
10	32	0.190	7 (0.201)	21 (0.159)	20 (0.161)	19 (0.166)	0.305	0.128	0.040	0.061	0.372	0.104	0.040	0 047	0.346	0.133	0.040	0.076
	24			26 (0.147)	25 (0.1495)	22 (0.157)												
12	28	0.216	1 (0.228)	15 (0.180)	14 (01.82)	13 (0.185)	0.345	0.145	0.051	0.069	0.424	0 120	0.051	0.053	0.394	0.151	0.051	0.085
	24			17 (0.173)	16 (0.177)	15 (0.180)												
1/4	28	0.250	*H* (0.266)	3 (0 213)	3 (0.213)	2 (0.221)	0.401	0.166	0.051	0.079	0.492	0.139	0.051	0.060	0.457	0.175	0.051	0.096
	20			8 (0 199)	6 (0.204)	5 (0.2055)												
5/16	24	0.3125	*Q* (0.332)	*I* (0.272)	*I* (0.272)	*J* (0.277)	0.504	0.206	0.072	0.096	0.618	0.176	0.072	0.075	0.574	0.219	0.072	0.118
	18			*F* (0.257)	*G* (0.261)	17/64												
3/8	24	0.375	*X* (0.397)	*Q* (0.332)	*Q* (0 332)	*R* (0.339)	0.606	0.246	0.072	0.114	0.742	0.211	0.072	0.090	0.689	0.262	0.072	0.140
	16			5/16	*O* (0.316)	*P* (0.323)												
7/16	20	0.4375	15/32	*W* (0.386)	25/64	*X* (0.397)	0.709	0.287	0.102	0.132	0.868	0.248	0.102	0.103	0.805	0.305	0.102	0.161
	14			23/64	(0 368)	*V* (0.377)												
1/2	20	0.500	17/32	29/64	29/64	29/64	0.815	0.328	0.102	0 150	0.992	0.283	0.102	0.118	0.920	0.347	0.102	0.183
	13			27/64	27/64	7/16												
5/8	11	0 625		17/32	17/32	9/16												
3/4	10	0.750		41/64	21/32	43/64												
7/8	9	0 875		49/64	25/32	51/64												
1	8	1.000		7/8	57/64	29/32												

Kollsman Instrument Company, Inc.

Hanger Bolts

HANGER BOLTS—PLAIN OR RIBBED SHOULDER
(In Inches)

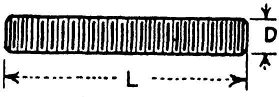


D Nominal Diameter of Bolt	*L* Over-all Length of Bolt	*B* Bolt Thread* Length	*T* Lag Thread† Length	*S* Length of Shoulder Ribbed or Plain	*R* Length‡ of Ribs
¼ inch to ⅞ inch inclusive	2 to 2½	⅝	Lag end of bolt shall be threaded from end to shoulder (see Note).	½	$\frac{5}{32}$
	2¾ to 3	¾		⅝	$\frac{5}{32}$
	3¼ to 3¾	⅞		¾	$\frac{5}{32}$
	4 to 4¾	1		⅞	$\frac{5}{32}$
	5 to 5¾	1⅛		1	$\frac{5}{32}$
	6 to 6½	1¼		1¾	$\frac{5}{32}$
	Above 6½	1⅜			$\frac{5}{32}$

* American Standard coarse-thread series—threaded to shoulder.
† Form of lag thread shall be in accordance with page 702.
‡ On the ribbed-shoulder type, the length of ribs *R* is included in the length of shoulder.

Continuous-Thread Stud Bolt

(Flange Stud)



DIMENSIONS

D = nominal size or diameter of stud bolt.
L = length of stud bolt over all.
"*Y*"-Points on both ends shall be chamfered.

THREADS

The threads shall be American Standard and continuous from end to end.

RECOMMENDED ORDER FOR SPECIFYING DIMENSIONS

To avoid possible misunderstanding when specifying dimensions of continuous-thread stud bolts, it is recommended that they be given in the following order—*D* × *L*.

STANDARD SIZES OF WRENCH HEAD BOLTS AND NUTS AND WRENCH OPENINGS

Proposed by the A.S.A., A.S.M.E., and S.A.E., May, 1930.

These standards are intended for general use by all industries to replace the various existing standards now in use.

These tables are believed to be acceptable to various industries and will cause little disturbance of present practice. Wherever possible, the U. S. standard sizes of bolt heads and nuts have been reduced to some existing shop standard after giving consideration to theoretical analysis of stresses in bolts and nuts and making tests of samples. Deviations from theoretical sizes have been made in order to keep the number of wrench openings small and to conform to manufacturing processes. The greatest possible tolerances have been allowed but will usually be much less in practice.

The number of wrench openings required have been reduced through simplication of outside dimensions of bolt heads and nuts and elimination of sizes little used. This has caused deviations from results calculated by formulas for sizes of bolt heads and nuts due to eliminating the thirty-seconds from all sizes.

The sizes of bolt heads and nuts are intended to supersede all existing standards which have grown up for commercial standard bolt heads and nuts.

It will be noted that the maximum sizes of both finished and rough products are the same, so that wrenches are applicable interchangeably to either class of bolt head or nut. In all cases the *nominal or basic* widths across flats of bolt heads and nuts have been taken as *maximum* sizes, and the tolerances on bolt heads and nuts are minus only.

The *minimum* wrench openings provide a positive *clearance* between maximum nut and minimum wrench and the tolerances on *wrench openings* are *plus* only. This insures a fit of the wrench to the bolt head and nut. The tolerance allowed the wrench manufacturer has been made as great as is possible without causing the deformation of the corners of bolt heads or nuts. The number of wrench openings is reduced.

TABLE 17.—ROUGH AND SEMI-FINISHED SQUARE AND HEXAGONAL REGULAR BOLT HEADS

(All Dimensions in Inches. *D* = Diameter of Bolts)

Diameter of Bolt *D*		Width across Flats			Minimum Width across Corners		Height		
		Maximum		Minimum	Hexagon	Square	Nominal	Maximum	Minimum
1/4	0.2500	3/8	0.3750	0.363	0.414	0.498	11/64	0.188	0.156
5/16	0.3125	1/2	0.5000	0.484	0.552	0.665	13/64	0.220	0.186
3/8	0.3750	9/16	0.5625	0.544	0.620	0.747	1/4	0.268	0.232
7/16	0.4375	5/8	0.6250	0.603	0.687	0.828	19/64	0.316	0.278
1/2	0.5000	3/4	0.7500	0.725	0.827	0.995	21/64	0.348	0.308
9/16	0.5625	7/8	0.8750	0.847	0.966	1.163	3/8	0.396	0.354
5/8	0.6250	15/16	0.9375	0.906	1.033	1.244	27/64	0.444	0.400
3/4	0.7500	1 1/8	1.1250	1.088	1.240	1.494	1/2	0.524	0.476
7/8	0.8750	1 5/16	1.3125	1.269	1.447	1.742	19/32	0.620	0.568
1	1.0000	1 1/2	1.5000	1.450	1.653	1.991	21/32	0.684	0.628
1 1/8	1.1250	1 11/16	1.6875	1.631	1.859	2.239	3/4	0.780	0.720
1 1/4	1.2500	1 7/8	1.8750	1.813	2.067	2.489	27/32	0.876	0.812
1 1/2	1.5000	2 1/4	2.2500	2.175	2.480	2.986	1	1.036	0.964
1 3/4	1.7500	2 5/8	2.6250	2.538	2.893	3.485	1 5/32	1.196	1.116
2	2.0000	3	3.0000	2.900	3.306	3.982	1 11/32	1.388	1.300
2 1/4	2.2500	3 3/8	3.3750	3.263	3.720	4.480	1 1/2	1.548	1.452
2 1/2	2.5000	3 3/4	3.7500	3.625	4.133	4.977	1 21/32	1.708	1.604
2 3/4	2.7500	4 1/8	4.1250	3.988	4.546	5.476	1 53/64	1.885	1.773
3	3.0000	4 1/2	4.5000	4.350	4.959	5.973	2	2.060	1.960

Formulas

Width across flats of rough and semifinished regular bolt heads shall be 1½ *D* with adjustments in the 1/16-inch sizes to eliminate 1/32-inch size wrench openings.

Tolerance for width across flats shall be minus 0.05 *D*.

Minimum width across rounded corners of hexagon equals 1.14 times minimum width across flats.

Height of head shall be ⅔ *D*.

The top of bolt head shall be flat and chamfered, angle of chamfer with top surface 30 degrees for hexagon heads and 25 degrees for square heads; diameter of top flat circle shall be 100 per cent of the nominal width across flats.

Tolerance on top flat circle shall be minus 15 per cent.

Rough and semifinished regular bolt heads shall be at right angles to the body within 3 degrees and concentric with the body within a tolerance of 3 per cent of the distance across flats.

Width across flats shall be measured at the bottom of the bolt head.

Taper of sides of bolt heads shall not exceed 4 degrees.

Minimum width across rounded corners of square equals 1.373 times minimum width across flats.

TABLE 18.—DIMENSIONS OF REGULAR BOLT HEADS
Semifinished, Hexagon. All Dimensions in Inches

Nominal Size or Basic Major Diameter of Thread		Width across Flats			Width across Corners	Height		
		Maximum (Basic)		Minimum	Minimum	Nominal	Maximum	Minimum
1/4	0.2500	3/8	0.3750	0.362	0.413	5/32	0.172	0.140
5/16	0.3125	1/2	0.5000	0.484	0.552	3/16	0.205	0.171
3/8	0.3750	9/16	0.5625	0.544	0.620	15/64	0.252	0.216
7/16	0.4375	5/8	0.6250	0.603	0.687	9/32	0.300	0.262
1/2	0.5000	3/4	0.7500	0.725	0.826	19/64	0.317	0.277
9/16	0.5625	7/8	0.8750	0.847	0.966	11/32	0.365	0.323
5/8	0.6250	15/16	0.9375	0.906	1.033	25/64	0.413	0.369
3/4	0.7500	1 1/8	1.1250	1.088	1.240	15/32	0.493	0.445
7/8	0.8750	1 5/16	1.3125	1.269	1.447	9/16	0.589	0.536
1	1.0000	1 1/2	1.5000	1.450	1.653	19/32	0.622	0.566
1 1/8	1.1250	1 11/16	1.6875	1.631	1.859	11/16	0.718	0.658
1 1/4	1.2500	1 7/8	1.8750	1.812	2.066	25/32	0.813	0.749
1 3/8	1.3750	2 1/16	2.0625	1.994	2.273	27/32	0.878	0.810
1 1/2	1.5000	2 1/4	2.2500	2.175	2.480	15/16	0.974	0.902
1 5/8	1.6250	2 7/16	2.4375	2.356	2.686	1 1/32	1.069	0.993
1 3/4	1.7500	2 5/8	2.6250	2.538	2.893	1 3/32	1.134	1.054
1 7/8	1.8750	2 13/16	2.8125	2.719	3.100	1 3/16	1.230	1.146
2	2.0000	3	3.0000	2.900	3.306	1 7/32	1.263	1.175
2 1/4	2.2500	3 3/8	3.3750	3.262	3.719	1 3/8	1.423	1.327
2 1/2	2.5000	3 3/4	3.7500	3.625	4.133	1 17/32	1.583	1.479
2 3/4	2.7500	4 1/8	4.1250	3.988	4.546	1 11/16	1.744	1.632
3	3.0000	4 1/2	4.5000	4.350	4.959	1 7/8	1.935	1.815

A.S.A. Standard, March, 1940.

Regular bolt heads are for general use.

Semifinished bolt heads are finished under head.

Taper of the bolt heads (angle between one side and the axis) shall not exceed 2 degrees, the specified width across flats being the largest dimension.

Top of bolt heads shall be flat and chamfered; angle of chamfer with top surface shall be 30 degrees; diameter of top circle shall be the maximum width across flats, within a tolerance of minus 15 per cent.

Bearing surface shall be plain or washer faced. The thickness of the washer face shall be 1/64 inch included in the head height and diameter of the washer face shall be the maximum width across flats within a tolerance of minus 5 per cent.

Bearing surface shall be at right angles to the axis of the body of the bolt within a tolerance of 2 degrees for 1-inch bolts, or smaller, and 1 degree for bolts larger than 1 inch and concentric with the axis of the body within a tolerance of 3 per cent of the maximum width across flats.

Maximum radius under head of bolt for sizes 1/4 to 1/2 inch shall be 1/32; for sizes 9/16 to 1 inch shall be 1/16; for sizes 1 1/8 to 2 inches shall be 1/8; for sizes 2 1/4 to 3 inches shall be 3/16.

Finished regular bolt heads when specified shall be made to the dimensions and tolerances given for the semifinished product; degree and character of finish to be specified in each case.

TABLE 19.—FINISHED HEXAGONAL CAP SCREW HEADS
(All Dimensions in Inches. D = Diameter of Bolts)

Diameter of Screw D		Width across Flats			Minimum Width across Corners	Height		
		Maximum		Minimum		Nominal	Maximum	Minimum
$\frac{1}{4}$	0.2500	$\frac{7}{16}$	0.4375	0.428	0.488	$\frac{3}{16}$	0.194	0.181
$\frac{5}{16}$	0.3125	$\frac{1}{2}$	0.5000	0.489	0.557	$\frac{15}{64}$	0.242	0.227
$\frac{3}{8}$	0.3750	$\frac{9}{16}$	0.5625	0.551	0.628	$\frac{9}{32}$	0.289	0.273
$\frac{7}{16}$	0.4375	$\frac{5}{8}$	0.6250	0.612	0.698	$\frac{21}{64}$	0.337	0.319
$\frac{1}{2}$	0.5000	$\frac{3}{4}$	0.7500	0.737	0.840	$\frac{3}{8}$	0.385	0.365
$\frac{9}{16}$	0.5625	$\frac{13}{16}$	0.8125	0.798	0.910	$\frac{27}{64}$	0.433	0.411
$\frac{5}{8}$	0.6250	$\frac{7}{8}$	0.8750	0.860	0.980	$\frac{15}{32}$	0.481	0.457
$\frac{3}{4}$	0.7500	1	1.0000	0.983	1.121	$\frac{9}{16}$	0.576	0.549
$\frac{7}{8}$	0.8750	$1\frac{1}{8}$	1.1250	1.106	1.261	$\frac{21}{32}$	0.672	0.641
1	1.0000	$1\frac{5}{16}$	1.3125	1.292	1.473	$\frac{3}{4}$	0.768	0.733
$1\frac{1}{8}$	1.1250	$1\frac{1}{2}$	1.5000	1.477	1.684	$\frac{27}{32}$	0.863	0.824
$1\frac{1}{4}$	1.2500	$1\frac{11}{16}$	1.6875	1.663	1.896	$\frac{15}{16}$	0.959	0.916

Formulas

Width across flats of cap screw heads shall be as follows:

Diameter of Bolt	Width across Flats
$\frac{1}{4}$ to $\frac{7}{16}$	$D + \frac{3}{16}$
$\frac{1}{2}$ to $\frac{7}{8}$	$D + \frac{1}{4}$
1	$D + \frac{5}{16}$
$1\frac{1}{8}$	$D + \frac{3}{8}$
$1\frac{1}{4}$	$D + \frac{7}{16}$

Tolerance for width across flats shall be minus 0.015 D plus 0.006.

Height of heads shall be $\frac{3}{4}$ D.

Tolerance for height of heads shall be 0.030 D + 0.005.

Minimum width across rounded corners of hexagon equals 1.14 times minimum width across flats.

The finished top shall be flat and chamfered, angle of chamfer with top surface 30 degrees, diameter of top flat circle shall be 100 per cent of the nominal width across flats.

Tolerance in diameter of top flat circle shall be minus 15 per cent.

Cap screw heads shall be at right angles to the body within 2 degrees and concentric with the body within a tolerance of 3 per cent of the distance across the flats.

All cap screws shall be washer faced. The height of the head shall be the distance from top of head to bearing surface. The thickness of washer face shall be $\frac{1}{64}$ inch. The bearing surface of washer face shall be 100 per cent of the nominal width across flats.

Tolerance in diameter of circle of washer face shall be plus or minus 5 per cent.

TABLE 20.—SET SCREW HEADS—SQUARE

(All Dimensions in Inches. D = Diameter of Bolts)

Diameter of Screw D		Width across Flats			Height		
		Maximum		Minimum	Nominal	Maximum	Minimum
$\frac{1}{4}$	0.2500	$\frac{1}{4}$	0.2500	0.241	$\frac{3}{16}$	0.197	0.179
$\frac{5}{16}$	0.3125	$\frac{5}{16}$	0.3125	0.302	$\frac{15}{64}$	0.245	0.224
$\frac{3}{8}$	0.3750	$\frac{3}{8}$	0.3750	0.362	$\frac{9}{32}$	0.293	0.270
$\frac{7}{16}$	0.4375	$\frac{7}{16}$	0.4375	0.423	$\frac{21}{64}$	0.341	0.315
$\frac{1}{2}$	0.5000	$\frac{1}{2}$	0.5000	0.484	$\frac{3}{8}$	0.389	0.361
$\frac{9}{16}$	0.5625	$\frac{9}{16}$	0.5625	0.545	$\frac{27}{64}$	0.437	0.407
$\frac{5}{8}$	0.6250	$\frac{5}{8}$	0.6250	0.607	$\frac{15}{32}$	0.485	0.452
$\frac{3}{4}$	0.7500	$\frac{3}{4}$	0.7500	0.729	$\frac{9}{16}$	0.582	0.544
$\frac{7}{8}$	0.8750	$\frac{7}{8}$	0.8750	0.852	$\frac{21}{32}$	0.678	0.635
1	1.0000	1	1.0000	0.974	$\frac{3}{4}$	0.774	0.726
$1\frac{1}{8}$	1.1250	$1\frac{1}{8}$	1.1250	1.097	$\frac{27}{32}$	0.870	0.817
$1\frac{1}{4}$	1.2500	$1\frac{1}{4}$	1.2500	1.219	$\frac{15}{16}$	0.967	0.909
$1\frac{1}{2}$	1.5000	$1\frac{1}{2}$	1.5000	1.464	$1\frac{1}{8}$	1.159	1.091

Formulas

Width across flats of set screw heads shall be equal to diameter of screw (D).

Tolerance for width across flats shall be minus $0.020\,D + 0.006$ (except for $\frac{1}{4}$ and $\frac{5}{16}$).

Height of set screw heads shall be $\frac{3}{4}\,D$.

Width of neck under head to be not over 2 times the pitch of the thread.

The radius of the crown of the head is to be $2\frac{1}{2}\,D$.

When head is not necked, it must be beveled not more than 40 degrees under the head.

Minimum width across rounded corners of square equals 1.373 times minimum width across flats.

TABLE 21.—DIMENSIONS OF REGULAR NUTS AND REGULAR JAM NUTS

Unfinished, Square and Hexagon (Jam Nuts, Hexagonal Only). All Dimensions in Inches

Nominal Size or Basic Major Diameter of Thread	Width across Flats		Thickness Regular Nuts			Thickness Regular Jam Nuts		
	Maximum (Basic)	Minimum	Nominal	Maximum	Minimum	Nominal	Maximum	Minimum
$\frac{1}{4}$ 0.2500	$\frac{7}{16}$ 0.4375	0.425	$\frac{7}{32}$	0.235	0.203	$\frac{5}{32}$	0.172	0.140
$\frac{5}{16}$ 0.3125	$\frac{9}{16}$ 0.5625	0.547	$\frac{17}{64}$	0.283	0.249	$\frac{3}{16}$	0.204	0.170
$\frac{3}{8}$ 0.3750	$\frac{5}{8}$ 0.6250	0.606	$\frac{21}{64}$	0.346	0.310	$\frac{7}{32}$	0.237	0.201
$\frac{7}{16}$ 0.4375	$\frac{3}{4}$ 0.7500	0.728	$\frac{3}{8}$	0.394	0.356	$\frac{1}{4}$	0.269	0.231
$\frac{1}{2}$ 0.5000	$\frac{13}{16}$ 0.8125	0.788	$\frac{7}{16}$	0.458	0.418	$\frac{5}{16}$	0.332	0.292
$\frac{9}{16}$ 0.5625	$\frac{7}{8}$ 0.8750	0.847	$\frac{1}{2}$	0.521	0.479	$\frac{11}{32}$	0.365	0.323
$\frac{5}{8}$ 0.6250	1 1.0000	0.969	$\frac{35}{64}$	0.569	0.525	$\frac{3}{8}$	0.397	0.353
$\frac{3}{4}$ 0.7500	$1\frac{1}{8}$ 1.1250	1.088	$\frac{21}{32}$	0.680	0.632	$\frac{7}{16}$	0.462	0.414
$\frac{7}{8}$ 0.8750	$1\frac{5}{16}$ 1.3125	1.269	$\frac{49}{64}$	0.792	0.740	$\frac{1}{2}$	0.526	0.474
1 1.0000	$1\frac{1}{2}$ 1.5000	1.450	$\frac{7}{8}$	0.903	0.847	$\frac{9}{16}$	0.590	0.534
$1\frac{1}{8}$ 1.1250	$1\frac{11}{16}$ 1.6875	1.631	1	1.030	0.970	$\frac{5}{8}$	0.655	0.595
$1\frac{1}{4}$ 1.2500	$1\frac{7}{8}$ 1.8750	1.812	$1\frac{3}{32}$	1.126	1.062	$\frac{3}{4}$	0.782	0.718
$1\frac{3}{8}$ 1.3750	$2\frac{1}{16}$ 2.0625	1.994	$1\frac{13}{64}$	1.237	1.169	$\frac{13}{16}$	0.846	0.778
$1\frac{1}{2}$ 1.5000	$2\frac{1}{4}$ 2.2500	2.175	$1\frac{5}{16}$	1.348	1.276	$\frac{7}{8}$	0.911	0.839
$1\frac{5}{8}$ 1.6250	$2\frac{7}{16}$ 2.4375	2.356	$1\frac{27}{64}$	1.460	1.384	$\frac{15}{16}$	0.976	0.900
$1\frac{3}{4}$ 1.7500	$2\frac{5}{8}$ 2.6250	2.538	$1\frac{17}{32}$	1.571	1.491	1	1.040	0.960
$1\frac{7}{8}$ 1.8750	$2\frac{13}{16}$ 2.8125	2.719	$1\frac{41}{64}$	1.683	1.599	$1\frac{1}{16}$	1.104	1.020
2 2.0000	3 3.0000	2.900	$1\frac{3}{4}$	1.794	1.706	$1\frac{1}{8}$	1.169	1.081
$2\frac{1}{4}$ 2.2500	$3\frac{3}{8}$ 3.3750	3.262	$1\frac{31}{32}$	2.017	1.921	$1\frac{1}{4}$	1.298	1.202
$2\frac{1}{2}$ 2.5000	$3\frac{3}{4}$ 3.7500	3.625	$2\frac{3}{16}$	2.240	2.136	$1\frac{1}{2}$	1.552	1.448
$2\frac{3}{4}$ 2.7500	$4\frac{1}{8}$ 4.1250	3.988	$2\frac{13}{32}$	2.462	2.350	$1\frac{5}{8}$	1.681	1.569
3 3.0000	$4\frac{1}{2}$ 4.5000	4.350	$2\frac{5}{8}$	2.685	2.565	$1\frac{3}{4}$	1.810	1.690

A.S.A. Standard, March, 1940.

Regular nuts are for general use.

Unfinished nuts are not finished on any surface but are threaded.

Taper of the sides of nuts (angle between one side and the axis) shall not exceed 2 degrees, the specified width across flats being the largest dimension.

Tops of nuts shall be flat and chamfered or (except in jam nuts) washer crowned. For flat and chamfered nuts the angle of chamfer with the top surface shall be 25 degrees for square and 30 degrees for hexagon; diameter of the top circle shall be the maximum width across flats within a tolerance of minus 15 per cent.

Bearing surface shall be at right angles to the axis of the threaded hole within a tolerance of 3 degrees for 1-inch nuts or smaller and 2 degrees for nuts larger than 1 inch.

TABLE 22.—DIMENSIONS OF REGULAR NUTS AND REGULAR JAM NUTS

Semifinished, Hexagon. All Dimensions in Inches

Nominal Size or Basic Major Diameter of Thread		Width across Corners	Thickness Regular Nuts			Thickness Regular Jam Nuts		
		Minimum	Nominal	Maximum	Minimum	Nominal	Maximum	Minimum
1/4	0.2500	0.485	13/64	0.219	0.187	9/64	0.157	0.125
5/16	0.3125	0.624	1/4	0.267	0.233	11/64	0.189	0.155
3/8	0.3750	0.691	5/16	0.330	0.294	13/64	0.221	0.185
7/16	0.4375	0.830	23/64	0.378	0.340	15/64	0.253	0.215
1/2	0.5000	0.898	27/64	0.442	0.402	19/64	0.317	0.277
9/16	0.5625	0.966	31/64	0.505	0.463	21/64	0.349	0.307
5/8	0.6250	1.104	17/32	0.553	0.509	23/64	0.381	0.337
3/4	0.7500	1.240	41/64	0.665	0.617	27/64	0.446	0.398
7/8	0.8750	1.447	3/4	0.776	0.724	31/64	0.510	0.458
1	1.0000	1.653	55/64	0.887	0.831	35/64	0.575	0.519
1 1/8	1.1250	1.859	31/32	0.999	0.939	39/64	0.639	0.579
1 1/4	1.2500	2.066	1 1/16	1.094	1.030	23/32	0.751	0.687
1 3/8	1.3750	2.273	1 11/64	1.206	1.138	25/32	0.815	0.747
1 1/2	1.5000	2.480	1 9/32	1.317	1.245	27/32	0.880	0.808
1 5/8	1.6250	2.686	1 25/64	1.429	1.353	29/32	0.944	0.868
1 3/4	1.7500	2.893	1 1/2	1.540	1.460	31/32	1.009	0.929
1 7/8	1.8750	2.100	1 39/64	1.651	1.567	1 1/32	1.073	0.989
2	2.0000	3.306	1 23/32	1.763	1.675	1 3/32	1.138	1.050
2 1/4	2.2500	3.719	1 59/64	1.970	1.874	1 13/64	1.251	1.155
2 1/2	2.5000	4.133	2 9/64	2.193	2.089	1 29/64	1.505	1.401
2 3/4	2.7500	4.546	2 23/64	2.415	2.303	1 37/64	1.634	1.522
3	3.0000	4.959	2 37/64	2.638	2.518	1 45/64	1.763	1.643

A.S.A. Standard, March, 1940.
Width across flats same as in Table 21.
Regular nuts are for general use.
Semifinished nuts are finished on bearing surface and threaded.

Taper of the sides of nuts (angle between one side and the axis) shall not exceed 2 degrees, the specified width across flats being the largest dimension.

Tops of nuts shall be flat and chamfered; angle of chamfer with the top surface shall be 30 degrees; diameter of top circle shall be the maximum width across flats within a tolerance of minus 15 per cent.

Bearing surface shall be washer faced or with chamfered corners. Thickness of the washer face shall be 1/64 inch included in the nut thickness; and diameter of washer face shall be the maximum width across flats within a tolerance of minus 5 per cent.

Bearing surface shall be at right angles to the axis of the threaded hole within a tolerance of 2 degrees for 1-inch nuts or smaller and 1 degree for nuts larger than 1 inch.

Finished regular nuts when specified shall be made to the dimensions given for the semifinished product; degree and character of finish to be specified in each case.

TABLE 23.—DIMENSIONS OF HEAVY NUTS AND HEAVY JAM NUTS Unfinished, Square and Hexagon (Jam Nuts, Hexagonal Only). All Dimensions in Inches

Nominal Size or Basic Major Diameter of Thread	Width across Flats		Thickness Heavy Nuts			Thickness Heavy Jam Nuts		
	Maximum (Basic)	Minimum	Nominal	Maximum	Minimum	Nominal	Maximum	Minimum
1/4 0.2500	1/2 0.5000	0.488	1/4	0.266	0.234	3/16	0.204	0.172
5/16 0.3125	19/32 0.5938	0.578	5/16	0.330	0.296	7/32	0.236	0.202
3/8 0.3750	11/16 0.6875	0.669	3/8	0.393	0.357	1/4	0.268	0.232
7/16 0.4375	25/32 0.7812	0.759	7/16	0.456	0.418	9/32	0.300	0.262
1/2 0.5000	7/8 0.8750	0.850	1/2	0.520	0.480	5/16	0.332	0.292
9/16 0.5625	15/16 0.9375	0.909	9/16	0.584	0.542	11/32	0.365	0.323
5/8 0.6250	1 1/16 1.0625	1.031	5/8	0.647	0.603	3/8	0.397	0.353
3/4 0.7500	1 1/4 1.2500	1.212	3/4	0.774	0.726	7/16	0.462	0.414
7/8 0.8750	1 7/16 1.4375	1.394	7/8	0.901	0.849	1/2	0.526	0.474
1 1.0000	1 5/8 1.6250	1.575	1	1.028	0.972	9/16	0.590	0.534
1 1/8 1.1250	1 13/16 1.8125	1.756	1 1/8	1.155	1.095	5/8	0.655	0.595
1 1/4 1.2500	2 2.0000	1.938	1 1/4	1.282	1.218	3/4	0.782	0.718
1 3/8 1.3750	2 3/16 2.1875	2.119	1 3/8	1.409	1.341	13/16	0.846	0.778
1 1/2 1.5000	2 3/8 2.3750	2.300	1 1/2	1.536	1.464	7/8	0.911	0.839
1 5/8 1.6250	2 9/16 2.5625	2.481	1 5/8	1.663	1.587	15/16	0.976	0.900
1 3/4 1.7500	2 3/4 2.7500	2.662	1 3/4	1.790	1.710	1	1.040	0.960
1 7/8 1.8750	2 15/16 2.9375	2.844	1 7/8	1.917	1.833	1 1/16	1.104	1.020
2 2.0000	3 1/8 3.1250	3.025	2	2.044	1.956	1 1/8	1.169	1.081
2 1/4 2.2500	3 1/2 3.5000	3.388	2 1/4	2.298	2.202	1 1/4	1.298	1.202
2 1/2 2.5000	3 7/8 3.8750	3.750	2 1/2	2.552	2.448	1 1/2	1.552	1.448
2 3/4 2.7500	4 1/4 4.2500	4.112	2 3/4	2.806	2.694	1 5/8	1.681	1.569
3 3.0000	4 5/8 4.6250	4.475	3	3.060	2.940	1 3/4	1.810	1.690
3 1/4 3.2500	5 5.0000	4.838	3 1/4	3.314	3.186	1 7/8	1.939	1.811
3 1/2 3.5000	5 3/8 5.3750	5.200	3 1/2	3.568	3.432	2	2.068	1.932
3 3/4 3.7500	5 3/4 5.7500	5.562	3 3/4	3.822	3.678	2 1/8	2.197	2.053
4 4.0000	6 1/8 6.1250	5.925	4	4.076	3.924	2 1/4	2.326	2.174

A.S.A. Standard, March, 1940.

Heavy nuts are for use where greater bearing surface is necessary.

Unfinished nuts are not finished on any surface but are threaded.

Taper of the sides of nuts (angle between one side and the axis) shall not exceed 2 degrees, the specified width across flats being the largest dimension.

Tops of nuts shall be flat and chamfered or (except jam nuts) washer crowned. For flat and chamfered nuts the angle of chamfer with the top surface shall be 25 degrees for square and 30 degrees for hexagon; diameter of the top circle shall be the maximum width across flats within a tolerance of minus 15 per cent.

Bearing surface shall be at right angles to the axis of the threaded hole within a tolerance of 3 degrees for 1-inch nuts or smaller and 2 degrees for nuts larger than 1 inch.

TABLE 24.—HEXAGONAL AND SQUARE MACHINE-SCREW NUTS AND STOVE-BOLT NUTS

(All Dimensions in Inches. D = Diameter of Bolts)

Diameter of Screw D		Width across Flats			Width across Corners of Hexagon	Thickness		
		Maximum		Minimum	Minimum	Nominal	Maximum	Minimum
No. 0	0.0600	$\frac{5}{32}$	0.1562	0.150	0.171	$\frac{3}{64}$	0.050	0.043
No. 1	0.0730	$\frac{5}{32}$	0.1562	0.150	0.171	$\frac{3}{64}$	0.050	0.043
No. 2	0.0860	$\frac{3}{16}$	0.1875	0.180	0.205	$\frac{1}{16}$	0.066	0.057
No. 3	0.0990	$\frac{3}{16}$	0.1874	0.180	0.205	$\frac{1}{16}$	0.066	0.057
No. 4	0.1120	$\frac{1}{4}$	0.2500	0.241	0.275	$\frac{3}{32}$	0.098	0.087
No. 5	0.1250	$\frac{5}{16}$	0.3125	0.302	0.344	$\frac{7}{64}$	0.114	0.102
No. 6	0.1380	$\frac{5}{16}$	0.3125	0.302	0.344	$\frac{7}{64}$	0.114	0.102
No. 8	0.1640	$\frac{11}{32}$	0.3437	0.332	0.378	$\frac{1}{8}$	0.130	0.117
No. 10	0.1900	$\frac{3}{8}$	0.3750	0.362	0.413	$\frac{1}{8}$	0.130	0.117
No. 12	0.2160	$\frac{7}{16}$	0.4375	0.423	0.482	$\frac{5}{32}$	0.161	0.148
$\frac{1}{4}$	0.2500	$\frac{7}{16}$	0.4375	0.423	0.482	$\frac{3}{16}$	0.193	0.178
$\frac{5}{16}$	0.3125	$\frac{9}{16}$	0.5625	0.545	0.621	$\frac{7}{32}$	0.225	0.208
$\frac{3}{8}$	0.3750	$\frac{5}{8}$	0.6250	0.607	0.692	$\frac{1}{4}$	0.257	0.239

Formulas

Width across flats of machine screw and stove-bolt nuts shall be as follows: diameter of screw $\frac{1}{4}$ to $\frac{3}{8}$ inch; width across flats = $1\frac{1}{2} D + \frac{1}{16}$ inch, with adjustments in the $\frac{1}{16}$-inch sizes to eliminate $\frac{1}{32}$-inch-size wrench openings.

Minimum width across rounded corners of square equals 1.373 times minimum width across flats; of hexagon 1.14 times minimum.

TABLE 25.—OPEN-END WRENCH OPENINGS FOR REGULAR, HEAVY- AND LIGHT-SERIES BOLTS AND NUTS
All Dimensions in Inches

Nominal Size of Wrench, also Basic or Maximum Width across Flats, Bolt Heads, and Nuts	Allowance between Bolt Head or Nut and Jaws of Wrench	Wrench Openings			Nominal Bolt Diameter						
					Regular Series		Heavy Series	Light Series			
		Minimum	Tolerance	Maximum	Bolts, Unfinished, Semi-finished, and Finished	Nuts, Jam Nuts, and Slotted Nuts, Unfinished, Semi-finished, and Finished	Bolts, Nuts, Jam Nuts, Slotted Nuts, Unfinished, Semi-finished, and Finished	Nuts, Jam Nuts, Castle Nuts, and Slotted Nuts	Cap Screws	Set Screws	Machine-screw Nuts and Stove-bolt Nuts
5/32 0.1562	0.002	0.158	0 005	0.163	...	...	...	...	...	...	No. 0 & No. 1
3/16 0.1875	0.002	0.190	0.005	0.195	...	...	...	...	...	...	No. 2 & No. 3
1/4 0.2500	0.002	0.252	0.005	0.257	...	...	...	...	...	1/4	No. 4
5/16 0.3125	0.003	0.316	0.006	0.322	...	...	...	...	...	5/16	No. 5 & No. 6
11/32 0.3438	0.003	0.347	0.006	0.353	...	...	...	...	...	...	No. 8
3/8 0.3750	0.003	0.378	0.006	0.384	1/4	...	...	...	...	3/8	No. 10
7/16 0.4375	0.003	0.440	0.006	0.446	...	1/4	...	1/4	1/4	7/16	No. 12 & 1/4
1/2 0.5000	0.004	0.504	0.006	0.510	5/16	...	1/4	5/16	5/16	1/2	
9/16 0.5625	0.004	0.566	0.007	0.573	3/8	5/16	...	3/8	3/8	9/16	5/16
19/32 0.5938	0.004	0.598	0.007	0.605	...	...	5/16				
5/8 0.6250	0.004	0.629	0.007	0.636	7/16	3/8	...	7/16	7/16	5/8	3/8
11/16 0.6875	0.004	0.692	0.007	0.699	...	...	3/8				
3/4 0.7500	0.005	0.755	0.008	0.763	1/2	7/16	...	1/2	1/2	3/4	
25/32 0.7812	0.005	0.786	0.008	0.794	...	...	7/16				
13/16 0.8125	0.005	0.818	0.008	0.826	...	1/2	...	...	9/16		
7/8 0.8750	0.005	0.880	0 008	0.888	9/16	9/16	1/2	9/16	5/8	7/8	
15/16 0.9375	0.006	0.944	0.009	0.953	5/8	...	9/16	5/8			
1 1.0000	0.006	1.006	0.009	1.015	...	5/8	...	...	3/4	1	
1 1/16 1.0625	0.006	1.068	0 009	1.077	...	...	5/8	3/4			
1 1/8 1.1250	0.007	1.132	0.010	1.142	3/4	3/4	...	...	7/8	1 1/8	
1 1/4 1.2500	0.007	1.257	0.010	1.267	...	...	3/4	7/8	...	1 1/4	
1 5/16 1.3125	0.008	1.320	0.011	1.331	7/8	7/8	...	...	1		
1 3/8 1.3750	0.008	1.383	0.011	1.394	...	...	...	...	...	1 3/8	
1 7/16 1 4375	0.008	1.446	0 011	1 457	.	...	7/8	1			

1½	1.5000	0.008	1.508	0.012	1.520	1	1	...	...	1⅛	1½
1⅝	1.6250	0.009	1.634	0.012	1.646	...	...	1	1⅛		
1 11/16	1.6875	0.009	1.696	0.012	1.708	1⅛	1⅛	...	...	1¼	
1 13/16	1.8125	0.010	1.822	0.013	1.835	...	...	1⅛	1¼		
1⅞	1.8750	0.010	1.885	0.013	1.898	1¼	1¼				
2	2.0000	0.011	2.011	0.014	2.025	...	...	1¼	1⅜		
2 1/16	2.0625	0.011	2.074	0.014	2.088	1⅜	1⅜				
2 3/16	2.1875	0.012	2.200	0.015	2.215	...	...	1⅜	1½		
2¼	2.2500	0.012	2.262	0.015	2.277	1½	1½				
2⅜	2.3750	0.013	2.388	0.016	2.404	...	...	1½			
2 7/16	2.4375	0.013	2.450	0.016	2.466	1⅝	1⅝				
2 9/16	2.5625	0.014	2.576	0.017	2.593	...	...	1⅝			
2⅝	2.6250	0.014	2.639	0.017	2.656	1¾	1¾				
2¾	2.7500	0.014	2.766	0.017	2.783	...	...	1¾			
2 13/16	2.8125	0.015	2.827	0.018	2.845	1⅞	1⅞				
2 15/16	2.9375	0.016	2.954	0.019	2.973	...	...	1⅞			
3	3.0000	0.016	3.016	0.019	3.035	2	2				
3⅛	3.1250	0.017	3.142	0.020	3.162	...	...	2			
3⅜	3.3750	0.018	3.393	0.021	3.414	2¼	2¼				
3½	3.5000	0.019	3.518	0.022	3.540	...	...	2¼			
3¾	3.7500	0.020	3.770	0.023	3.793	2½	2½				
3⅞	3.8750	0.020	3.895	0.023	3.918	...	...	2½			
4⅛	4.1250	0.022	4.147	0.025	4.172	2¾	2¾				
4¼	4.2500	0.022	4.272	0.025	4.297	...	...	2¾			
4½	4.5000	0.024	4.524	0.026	4.550	3	3				
4⅝	4.6250	0.024	4.649	0.027	4.676	...	...	3			
5	5.0000	0.026	5.026	0.029	5.055	...	...	3¼			
5⅜	5.3750	0.028	5.403	0.031	5.434	...	...	3½			
5¾	5.7500	0.030	5.780	0.033	5.813	...	...	3¾			
6⅛	6.1250	0.032	6.157	0.035	6.192	...	...	4			

A.S.A. Standard, March, 1940.

Wrenches shall be marked with the "Nominal Size of Wrench" which is equal to the basic or maximum width across flats of the corresponding bolt head or nut.

Allowance (minimum clearance) between maximum width across flats of nut or bolt head and jaws of wrench equals ($1.005W +$ 0.001). **Tolerance** on wrench opening equals plus ($0.005W + 0.004$) from minimum (W = nominal size of wrench).

TABLE 26.—LIGHT CASTLE NUTS, SEMIFINISHED HEXAGON[1]

Diameter of Bolt, in Inches		Width across Flats, in Inches			Width across Corners, in Inches	Thickness Over All, in Inches			Nom. Height of Flats, in Inches	Slot, in Inches	
Nom.	Max.	Nom.	Max.	Min.	Min.	Nom.	Max.	Min.		Width	Depth
1/4	0.2500	7/16	0.4375	0.428	0.488	9/32	0.288	0.275	3/16	5/64	3/32
5/16	0.3125	1/2	0.5000	0.489	0.557	21/64	0.335	0.321	15/64	5/64	3/32
3/8	0.3750	9/16	0.5625	0.551	0.628	13/32	0.414	0.398	9/32	1/8	1/8
7/16	0.4375	5/8	0.6250	0.612	0.698	29/64	0.462	0.444	21/64	1/8	1/8
1/2	0.5000	3/4	0.7500	0.737	0.840	9/16	0.573	0.553	3/8	1/8	3/16
9/16	0.5625	7/8	0.8750	0.861	0.982	39/64	0.620	0.598	27/64	5/32	3/16
5/8	0.6250	15/16	0.9375	0.922	1.051	23/32	0.731	0.707	15/32	5/32	1/4
3/4	0.7500	1 1/16	1.0625	1.045	1.191	13/16	0.826	0.799	9/16	5/32	1/4
7/8	0.8750	1 1/4	1.2500	1.231	1.403	29/32	0.921	0.891	21/32	5/32	1/4
1	1.0000	1 7/16	1.4375	1.417	1.615	1	1.017	0.983	3/4	5/32	1/4
1 1/8	1.1250	1 5/8	1.6250	1.602	1.826	1 5/32	1.173	1.139	27/32	7/32	5/16
1 1/4	1.2500	1 13/16	1.8125	1.788	2.038	1 1/4	1.272	1.229	15/16	7/32	5/16
1 3/8	1.3750	2	2.0000	1.973	2.249	1 3/8	1.402	1.348	1	7/32	5/16
1 1/2	1.5000	2 3/16	2.1875	2.159	2.461	1 1/2	1.525	1.475	1 1/8	1/4	3/8

For use with S.A.E. (American) Standard fine (NF) threads.
Tolerance for width across flats is minus ($0.015D + 0.006$) from nominal.
Minimum width across rounded corners equals 1.14 times minimum width across flats.
Height of the top circle above flats shall be not less than the minimum depth of the slot.
Bearing surface shall be washer faced; the thickness of the washer face shall be 1/64 inch; the diameter of the washer face shall be the maximum width across flats within a tolerance of minus 5 per cent.
Bearing surface shall be at right angles to the axis of the threaded hole within a tolerance of 2 degrees for 1-inch nuts or smaller and 1 degree for nuts larger than 1 inch

[1] Conforms with Table 17, American Standard B18.2–1933. Report of the Screw Threads Division, adopted July, 1926. Last revision, January, 1933.

SCREWS, BOLTS, AND NUTS

National Fine (S. A. E.) Standard

The length of the effective thread of screws and bolts shall be: 1½ diameter + ¼ inch. As bolts and screws conforming to these specifications are primarily intended for use with nuts, the oval end is not included in the nominal length.

All heads and nuts shall be semifinished. All screws and nuts shall be made of steel.

S.A.E. Standard bolts without slots or cotter-pin holes are made for stock. If slots, cotter-pin holes or case hardening are desired, these should be specified by the purchaser.

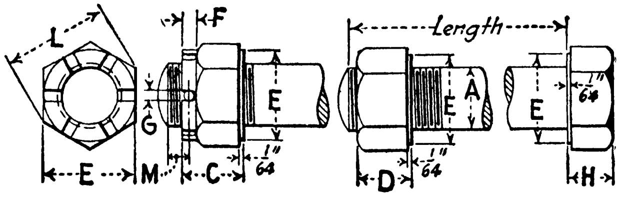
TABLE 27.—MACHINE SCREWS

American Screw Company, Standard Threads per Inch

No.	2	3	4	5	6	7	8	9	10	12
Threads per Inch	48 **56** 64	**48** 56	32, 32 **36,** 36 40, **40**		30 **32** 36	30 32	30 **32** 36	24, 24 30, 30 32, **32**		20 **24**

No.	14	16	18	20	22	24	26	28	30
Threads per Inch	18 **20** 24	16, 16 **18, 18** 20, 20		16, 16 **18, 18**		14 **16** 18	14, 16		

Boldface indicates threads used the most.



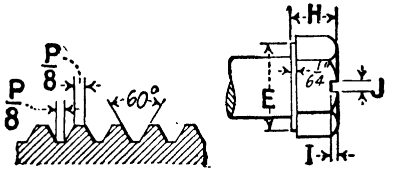
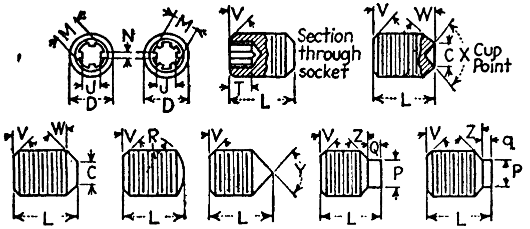


TABLE 28.—SCREW, BOLT, AND NUT DIMENSIONS—FINE THREAD (All Dimensions in Inches)

Diam. A −0.001 −0.003	Threads per Inch, B	C	D	E[1]	F	G[2]	H	I	J	K[3]	L	Cotter-Pin Hole	M
1/4	28	9/32	7/32	7/16	3/32	5/64	3/16	3/32	1/16	1/16	1/2	5/64	3/32
5/16	24	21/64	17/64	1/2	3/32	5/64	15/64	7/64	1/16	1/16	37/64	5/64	3/32
3/8	24	13/32	21/64	9/16	1/8	1/8	9/32	1/8	3/32	3/32	21/32	1/8	7/64
7/16	20	29/64	3/8	5/8	1/8	1/8	21/64	1/8	3/32	3/32	23/32	1/8	7/64
1/2	20	9/16	7/16	3/4	3/16	1/8	3/8	1/8	3/32	3/32	7/8	5/32	1/8
9/16	18	39/64	31/64	7/8	3/16	5/32	27/64	1/8	3/32	1/8	1 1/64	5/32	9/64
5/8	18	23/32	35/64	15/16	1/4	5/32	15/32	1/8	3/32	1/8	1 3/32	5/32	5/32
3/4	16	13/16	21/32	1 1/16	1/4	5/32	9/16	1/8	3/32	1/8	1 15/64	5/32	3/16
7/8	14	29/32	49/64	1 1/4	1/4	5/32	21/32	1/8	3/32	1/8	1 7/16	5/32	3/16
1	14	1	7/8	1 7/16	1/4	5/32	3/4	1/8	3/32	1/8	1 21/32	5/32	3/16
1 1/8	12	1 5/32	63/64	1 3/8	5/16	7/32	27/32	7/32	3/32	11/64	1 7/8	7/32	7/32
1 1/4	12	1 1/4	1 3/32	1 13/16	5/16	7/32	15/16	7/32	3/32	11/64	2 3/32	7/32	7/32
1 3/8	12	1 13/32	1 13/64	2	3/8	1/4	1 1/32	1/4	3/16	13/64	2 5/16	1/4	1/4
1 1/2	12	1 1/2	1 5/16	2 3/16	3/8	1/4	1 1/8	1/4	1/16	13/64	2 17/32	1/4	1/4

[1] For S. A. E. nuts, bolt and screw heads.
[2] Width of slots in nuts.
[3] Cotter-pin diameter.



Flat Point Oval Point Cone Point Full Dog Point Half Dog Point

Fluted Head Setscrews

TABLE 29.—DIMENSIONS OF FLUTED SOCKET SETSCREWS[1]

Number of Flutes	Socket Diameter Minor, *J*		Socket Diameter Major, *M*		Socket Land Width, *N*	
	Max.	Min.	Max.	Min.	Max.	Min.
4	0.053	0.052	0.071	0.070	0.022	0.021
4	0.056	0.055	0.079	0.078	0.025	0.024
6	0.079	0.078	0.098	0.097	0.022	0.021
6	0.097	0.095	0.113	0.111	0.027	0.025
6	0.097	0.095	0.113	0.111	0.027	0.025
6	0.127	0.125	0.147	0.145	0.032	0.030
6	0.160	0.158	0.185	0.183	0.041	0.040
6	0.190	0.188	0.219	0.217	0.052	0.050
6	0.221	0.219	0.256	0.254	0.062	0.060
6	0.254	0.252	0.297	0.295	0.072	0.070
6	0.254	0.252	0.297	0.295	0.072	0.070
6	0.315	0.312	0.380	0.377	0.092	0.089
6	0.386	0.383	0.463	0.460	0.112	0.109
6	0.506	0.503	0.600	0.597	0.142	0.139
6	0.568	0.564	0.654	0.650	0.157	0.153
6	0.568	0.564	0.654	0.650	0.157	0.153
6	0.631	0.627	0.790	0.786	0.184	0.180
6	0.631	0.627	0.790	0.786	0.184	0.180
6	0.756	0.752	0.958	0.954	0.221	0.217
6	1.007	1.003	1.275	1.271	0.298	0.294
6	1.007	1.003	1.275	1.271	0.298	0.294

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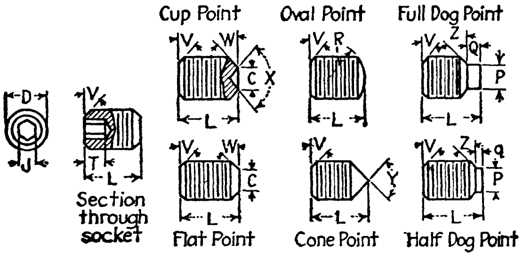
[1] All dimensions, except those shown in the table, are the same as for the Standard socket setscrews.

AMERICAN STANDARD SOCKET SETSCREWS

Adopted by American Standards Association



Hexhead Setscrews

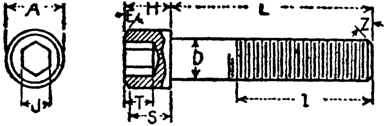
TABLE 30.—DIMENSIONS OF HEXAGONAL SOCKET SETSCREWS

Nominal Diameter, D	Cup and Flat Point Diameter, C			Oval Point Radius, R	Cone Point Angle, Y		Full-Dog Point and Half-Dog Point				Socket Width across Flats, J	
					118° ± 2° for These Lengths and Under	90° ± 2° for These Lengths and Over	Diameter, P		Full, Q	Half, q		
	Mean	Max.	Min.				Max.	Min.			Max.	Min.
5	$\frac{1}{16}$	0.067	0.057	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{3}{16}$	0.083	0.078	0.06	0.03	0.0635	$\frac{1}{16}$
6	0.069	0.074	0.064	$\frac{7}{64}$	$\frac{1}{8}$	$\frac{3}{16}$	0.092	0.087	0.07	0.03	0.0635	$\frac{1}{16}$
8	$\frac{5}{64}$	0.087	0.076	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	0.109	0.103	0.08	0.04	0.0791	$\frac{5}{64}$
10	$\frac{3}{32}$	0.102	0.088	$\frac{9}{64}$	$\frac{3}{16}$	$\frac{1}{4}$	0.127	0.120	0.09	0.04	0.0947	$\frac{3}{32}$

12	7/64	0.115	0.101	5/32	3/16	1/4	0.144	0.137	0.11	0.06	0.0947	3/32
1/4	1/8	0.132	0.118	3/16	1/4	5/16	5/32	0.149	1/8	1/16	0.1270	1/8
5/16	11/64	0.172	0.156	15/64	5/16	3/8	13/64	0.195	5/32	5/64	0.1582	5/32
3/8	13/64	0.212	0.194	9/32	3/8	7/16	1/4	0.241	3/16	3/32	0.1895	3/16
7/16	15/64	0.252	0.232	21/64	7/16	1/2	19/64	0.287	5/32	7/64	0.2207	7/32
1/2	9/32	0.291	0.270	3/8	1/2	9/16	11/32	0.334	1/4	1/8	0.2520	1/4
9/16	5/16	0.332	0.309	27/64	9/16	5/8	25/64	0.379	9/32	9/64	0.2520	1/4
5/8	23/64	0.371	0.347	15/32	5/8	3/4	15/32	0.456	5/16	5/32	0.3155	5/16
3/4	7/16	0.450	0.425	9/16	3/4	7/8	9/16	0.549	3/8	3/16	0.3780	3/8
7/8	33/64	0.530	0.502	21/32	7/8	1	21/32	0.642	7/16	7/32	0.5030	1/2
1	19/32	0.609	0.579	3/4	1	1 1/8	3/4	0.734	1/2	1/4	0.5655	9/16
1 1/8	43/64	0.689	0.655	27/32	1 1/8	1 1/4	27/32	0.826	9/16	9/32	0.5655	9/16
1 1/4	3/4	0.767	0.733	15/16	1 1/4	1 1/2	15/16	0.920	5/8	5/16	0.6290	5/8
1 3/8	53/64	0.848	0.808	1 1/32	1 3/8	1 5/8	1 1/32	1.011	11/16	11/32	0.6290	5/8
1 1/2	29/32	0.926	0.886	1 1/8	1 1/2	1 3/4	1 1/8	1.105	3/4	3/8	0.7540	3/4
1 3/4	1 1/16	1.086	1.039	1 5/16	1 3/4	2	1 5/16	1 289	7/8	7/16	1.0040	1
2	1 7/32	1.244	1.193	1 1/2	2	2 1/4	1 1/2	1.474	1	1/2	1.0040	1

Chamfer and point angles: *W* = 45 to 50 degrees; *X* = 113 to 123 degrees; *Y*, see table; *Z* = 35 to 40 degrees. Socket end chamfer; *V* = 35 to 40 degrees with flat. Length varies by 1/16 from 1/4 to 5/8 inch; by 1/8 from 5/8 to 1 inch; by 1/4 from 1 to 4 inches; by 1/2 from 4 to 6 inches.

AMERICAN STANDARD SOCKET CAPSCREWS



Hexhead Capscrews

TABLE 31.—DIMENSIONS OF HEXAGONAL SOCKET CAPSCREWS

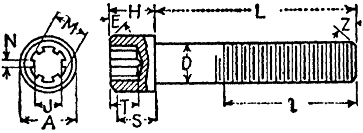
Body Diameter, *D*			Head Diameter, *A*		Head Height, *H*		Head-Side Height, *S*			Socket Width across Flats, *J*	
Nom.	Max	Min.	Max.	Min.	Max.	Min.	Nom.	Max.	Min.	Max.	Min.
8	0.1640	0.1613	$\frac{9}{32}$	0.276	0.164	0.160	0.1503	0.1522	0.1484	0.1270	$\frac{1}{8}$
10	0.1900	0.1867	$\frac{5}{16}$	0.306	0.190	0.185	0.1741	0.1765	0.1717	0.1582	$\frac{5}{32}$
12	0.2160	0.2127	$\frac{11}{32}$	0.337	0.216	0.211	0.1980	0.2005	0.1957	0.1582	$\frac{5}{32}$
$\frac{1}{4}$	0.2500	0.2464	$\frac{3}{8}$	0.367	$\frac{1}{4}$	0.244	0.2291	0.2317	0.2265	0.1895	$\frac{3}{16}$
$\frac{5}{16}$	0.3125	0.3084	$\frac{7}{16}$	0.429	$\frac{5}{16}$	0.306	0.2864	0.2894	0.2834	0.2207	$\frac{7}{32}$
$\frac{3}{8}$	0.3750	0.3705	$\frac{9}{16}$	0.553	$\frac{3}{8}$	0.368	0.3437	0.3469	0.3405	0.3155	$\frac{5}{16}$
$\frac{7}{16}$	0.4375	0.4326	$\frac{5}{8}$	0.615	$\frac{7}{16}$	0 430	0.4010	0.4046	0.3974	0.3155	$\frac{5}{16}$
$\frac{1}{2}$	0.5000	0.4948	$\frac{3}{4}$	0.739	$\frac{1}{2}$	0.492	0.4538	0.4620	0.4546	0.3780	$\frac{3}{8}$

Head chamfer *E* is 30 degrees with flat surface of head with edges slightly rounded. Socket depth *T* as great as possible. Length *L* varies by $\frac{1}{8}$ inch for lengths from $\frac{1}{4}$ to 1 inch; by $\frac{1}{4}$ inch from 1 to 4 inches; by $\frac{1}{2}$ inch from 4 to 6 inches. Screw-point chamfer *Z* may vary from 35 to 40 degrees with end surface. Thread length is usually more than half of *L*.

TABLE 31.—DIMENSIONS OF HEXAGONAL SOCKET CAPSCREWS.—*Continued*

Body Diameter, *D*			Head Diameter, *A*		Head Height, *H*		Head-Side Height, *S*			Socket Width across Flats, *J*	
Nom.	Max.	Min.	Max.	Min.	Max.	Min.	Nom.	Max.	Min.	Max.	Min.
9/16	0.5625	0.5569	13/16	0.801	9/16	0.554	0.5156	0.5196	0.5116	0.3780	3/8
5/8	0.6250	0.6191	7/8	0.863	5/8	0.616	0.5729	0.5771	0.5678	0.5030	1/2
3/4	0.7500	0.7436	1	0.987	3/4	0.741	0.6875	0.6920	0.6830	0.5655	9/16
7/8	0.8750	0.8680	1 1/8	1.111	7/8	0.865	0.8020	0.8069	0.7971	0.5655	9/16
1	1.0000	0.9924	1 5/16	1.297	1	0.989	0.9166	0.9220	0.9112	0.6290	5/8
1 1/8	1.1250	1.1165	1 1/2	1.483	1 1/8	1.113	1.0312	1.0372	1.0254	0.7540	3/4
1 1/4	1.2500	1.2415	1 3/4	1.733	1 1/4	1.238	1.1457	1.1516	1.1398	0.7540	3/4
1 3/8	1.3750	1.3649	1 7/8	1.855	1 3/8	1.361	1.2604	1.2675	1.2533	0.7540	3/4
1 1/2	1.5000	1.4899	2	1.979	1 1/2	1.485	1.3750	1.3821	1.3679	1.0040	1

Head chamfer *E* is 30 degrees with flat surface of head with edges slightly rounded. Socket depth *T* as great as possible. Length *L* varies by 1/8 inch for lengths from 1/4 to 1 inch; by 1/4 inch from 1 to 4 inches; by 1/2 inch from 4 to 6 inches. Screw-point chamfer *Z* may vary from 35 to 40 degrees with end surface. Thread length is usually more than half of *L*.



Fluted Head Capscrew

TABLE 32.—DIMENSIONS OF FLUTED SOCKET CAPSCREWS[1]

Size	Socket Diameter Minor, *J*		Socket Diameter Major, *M*		Width of Socket Land, *N*	
	Max.	Min.	Max.	Min.	Max.	Min.
8	0.127	0.125	0.147	0.145	0.035	0.033
10	0.127	0.125	0.147	0.145	0.035	0.033
12	0.160	0.158	0.185	0.183	0.042	0.040
$\frac{1}{4}$	0.190	0.188	0.219	0.217	0.052	0.050
$\frac{5}{16}$	0.221	0.219	0.256	0.254	0.062	0.060
$\frac{3}{8}$	0.312	0.310	0.380	0.378	0.092	0.090
$\frac{7}{16}$	0.312	0.310	0.380	0.378	0.092	0.090
$\frac{1}{2}$	0.386	0.383	0.463	0.460	0.112	0.109
$\frac{9}{16}$	0.386	0.383	0.463	0.460	0.112	0.109
$\frac{5}{8}$	0.506	0.503	0.600	0.597	0.142	0.139
$\frac{3}{4}$	0.568	0.564	0.654	0.650	0.157	0.153
$\frac{7}{8}$	0.568	0.564	0.654	0.650	0.157	0.153
1	0.631	0.627	0.790	0.786	0.184	0.180
1$\frac{1}{8}$	0.756	0.752	0.957	0.953	0.221	0.217
1$\frac{1}{4}$	0.756	0.752	0.957	0.953	0.221	0.217
1$\frac{3}{8}$	0.756	0.752	0.957	0.953	0.221	0.217
1$\frac{1}{2}$	1.007	1.003	1.275	1.271	0.298	0.294

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[1] All dimensions, except those shown in the table, are the same as for the Standard socket capscrews. All have 6 flutes.

SELF-TAPPING SCREWS

Hardened screws that form or tap the thread to hold them in place are now widely used, usually in sheet metal and in soft materials. Some are made with a fast helix that can be driven into place with a hammer. Screws of slower helix, that cut their own thread, are rotated into place by hand or power. They are made with heads of different shapes that conform with standards for machine screws, bolts, and capscrews. Table 33 shows the recommended hole sizes for Parker-Kalon screws in different materials. The two types of screws are shown in Fig 1.

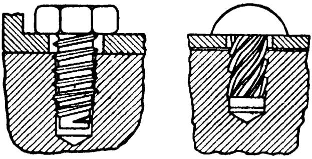
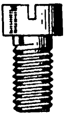


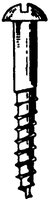
FIG. 1.—Self-tapping Screws

British Screwheads

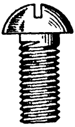
Terms used are by Guest, Keen, and Littlefolds, Ltd. Wood screws have a 90-deg. angle head.



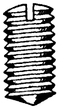
Cheese head



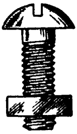
Wood screw



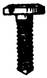
Round head



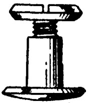
Grub screw



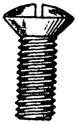
Mushroom head



Gallery screw



Band screw



Raised head

TABLE 33.—HOLE SIZES FOR PARKER-KALON TYPE *Z* HARDENED SELF-TAPPING SCREWS

Diameter of Screw*	In Sheet Steel					In Sheet Aluminum					In Castings of Aluminum, Zinc, White Metal, Etc.		In Bakelite, Durez, and Other Plastics		In Slate, Ebony, Asbestos, Etc.	
	Thickness of Metal		Pierced Hole	Drilled or Clean-Punched Hole		Thickness of Metal		Pierced Hole	Drilled or Clean-Punched Hole							
	No. of Gage (U. S. Standard)	Thickness in Dec. Parts of an Inch	Diam. Hole Required, in Inches	Diam. Hole Required, in Inches	Drill Size	No. of Gage (B. & S.)	Thickness in Dec. Parts of an Inch	Diam. Hole Required, in Inches	Diam. Hole Required, in Inches	Drill Size	Diam. Hole Required, in Inches	Drill Size	Diam. Hole Required, in Inches	Drill Size	Diam. Hole Required, in Inches	Drill Size
No. 2	28	0.015	.....	0.063	No. 52	22	0.025	.....	0.063	No. 52	0.078	No. 47	0.078	No. 47	0.076	No. 48
	26	0.018	.....	0.063	No. 52	20	0.031	.....	0.063	No. 52						
	24	0.025	.....	0.067	No. 51	18	0.040	.....	0.063	No. 52						
	22	0.031	.....	0.070	No. 50	16	0.050	.....	0.067	No. 51						
	20	0.037	.....	0.073	No. 49	14	0.064	.....	0.070	No. 50						
	18	0.050	.....	0.073	No. 49											
	16	0.062	.....	0.076	No. 48											
No. 4	28	0.015	0.086	0.086	No. 44	22	0.025	0.086			0.104	No. 37	0.099	No. 39	0.101	No. 38
	26	0.018	0.086	0.086	No. 44	20	0.031	0.093	0.086	No. 44						
	24	0.025	0.093	0.089	No. 43	18	0.040	0.093	0.086	No. 44						
	22	0.031	0.098	0.093	No. 42	16	0.050	.....	0.086	No. 44						
	20	0.037	0.100	0.093	No. 42	14	0.064	.....	0.089	No. 43						
	18	0.050	.....	0.096	No. 41	12	0.080	.....	0.089	No. 43						
	16	0.062	.....	0.099	No. 39	10	0.101	.....	0.093	No. 42						
	14	0.078	.....	0.101	No. 38											
	28	0.015	0.106	0.104	No. 37	22	0.025	0.110								
	26	0.018	0.106	0.104	No. 37	20	0.031	0.110	0.104	No. 37						
	24	0.025	0.106	0.106	No. 36	18	0.040	0.110	0.104	No. 37						
	22	0.031	0.110	0.106	No. 36	16	0.050	0.113	0.104	No. 37						

No. 6	20	0.037	0.110	0.110	No. 35	14	0.064	.....	0.106	No. 36	0.128	No. 30	0.128	No. 30	0.120	No. 31
	18	0.050	.....	0.111	No. 34	12	0.080	.....	0.110	No. 35						
	16	0.062	.....	0.116	No. 32	10	0.101	.....	0.111	No. 34						
	14	0.078	.....	0.120	No. 31	8	0.128	.....	0.113	No. 33						
	12	0.109	.....	0.128	No. 30	6	0.162	.....	0.116	No. 32						
						¼″	0.250	.....	0.120	No. 31						
No. 7	26	0.018	0.121	0.116	No. 32	22	0.025	0.121			0.144	No. 27	0.136	No. 29	0.136	No. 29
	24	0.025	0.121	0.116	No. 32	20	0.031	0.121	0.116	No. 32						
	22	0.031	0.121	0.116	No. 32	18	0.040	0.121	0.116	No. 32						
	20	0.037	0.121	0.116	No. 32	16	0.050	0.121	0.116	No. 32						
	18	0.050	0.121	0.120	No. 31	14	0.064	.....	0.120	No. 31						
	16	0.062	.....	0.128	No. 30	12	0.080	.....	0.128	No. 30						
	14	0.078	.....	0.136	No. 29	10	0.101	.....	0.136	No. 29						
	12	0.109	.....	0.140	No. 28	8	0.128	.....	0.136	No. 29						
						6	0.162	.....	0.136	No. 29						
						¼″	0.250	.....	0.140	No. 28						
No. 8	26	0.018	0.131	.....	......	22	0.025	0.120			0.152	No. 24	0.149	No. 25	0.147	No. 26
	24	0.025	0.131	0.116	No. 32	20	0.031	0.120								
	22	0.031	0.131	0.116	No. 32	18	0.040	0.131	0.120	No. 31						
	20	0.037	0.136	0.116	No. 32	16	0.050	0.136	0.128	No. 30						
	18	0.050	0.140	0.128	No. 30	14	0.064	.....	0.136	No. 29						
	16	0.062	.....	0.136	No. 29	12	0.080	.....	0.140	No. 28						
	14	0.078	.....	0.140	No. 28	10	0.101	.....	0.147	No. 26						
	12	0.109	.....	0.149	No. 25	8	0.128	.....	0.149	No. 25						
	⅛″	0.125	.....	0.149	No. 25	6	0.162	.....	0.152	No. 24						
	10	0.140	.....	0.152	No. 24	¼″	0.250	.....	0.152	No. 24						
						⅜″	0.375	.....	0.152	No. 24						
No. 10	26	0.018	0.144	0.144	No. 27	22	0.025	0.144			0.177	No. 16	0.177	No. 16	0.166	No. 19
	24	0.025	0.144	0.144	No. 27	20	0.031	0.144								
	22	0.031	0.144	0.144	No. 27	18	0.040	0.144	0.144	No. 27						
	20	0.037	0.147	0.144	No. 27	16	0.050	0.144	0.144	No. 27						
	18	0.050	0.155	0.144	No. 27	14	0.064	.....	0.144	No. 27						
	16	0.062	.....	0.152	No. 24	12	0.080	.....	0.147	No. 26						
	14	0.078	.....	0.157	No. 22	10	0.101	.....	0.147	No. 26						
	12	0.109	.....	0.161	No. 20	8	0.128	.....	0.154	No. 23						
	⅛″	0.125	.....	0.169	No. 18	6	0.162	.....	0.159	No. 21						
	10	0.140	.....	0.169	No. 18	¼″	0.250	.....	0.166	No. 19						
	8	0.171	.....	0.173	No. 17	⅜″	0.375	.....	0.166	No. 19						

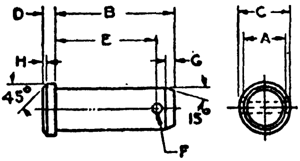
TABLE 33.—HOLE SIZES FOR PARKER-KALON TYPE *Z* HARDENED SELF-TAPPING SCREWS.—*Continued*

Diameter of Screw*	In Sheet Steel					In Sheet Aluminum					In Castings of Aluminum, Zinc, White Metal, Etc.		In Bakelite, Durez, and Other Plastics		In Slate, Ebony, Asbestos, Etc.	
	Thickness of Metal		Pierced Hole	Drilled or Clean-Punched Hole		Thickness of Metal		Pierced Hole	Drilled or Clean-Punched Hole							
	No. of Gage (U. S. Standard)	Thickness in Dec. Parts of an Inch	Diam. Hole Required, in Inches	Diam. Hole Required, in Inches	Drill Size	No. of Gage (B. & S.)	Thickness in Dec. Parts of an Inch	Diam. Hole Required, in Inches	Diam. Hole Required, in Inches	Drill Size	Diam. Hole Required, in Inches	Drill Size	Diam. Hole Required, in Inches	Drill Size	Diam. Hole Required, in Inches	Drill Size
No. 12	24	0.025	0.185	0.166	No. 19	22	0.025	0.161			0.199	No. 8	0.199	No. 8	0.196	No. 9
	22	0.031	0.185	0.166	No. 19	20	0.031	0.161								
	20	0.037	0.185	0.166	No. 19	18	0.040	0.161								
	18	0.050	0.185	0.169	No. 18	16	0.050	0.166	0.161	No. 20						
	16	0.062	.....	0.177	No. 16	14	0.064	.....	0.166	No. 19						
	14	0.078	.....	0.182	No. 14	12	0.080	.....	0.173	No. 17						
	12	0.109	.....	0.185	No. 13	10	0.101	.....	0.180	No. 15						
	$\frac{1}{8}''$	0.125	.....	0.196	No. 9	8	0.128	.....	0.182	No. 14						
	10	0.140	.....	0.196	No. 9	6	0.162	.....	0.189	No. 12						
	8	0.171	.....	0.201	No. 7	$\frac{1}{4}''$	0.250	.....	0.193	No. 10						
						$\frac{3}{8}''$	0.375	.....	0.199	No. 8						
No. 14	22	0.031	0.209	0.185	No. 13	22	0.025	0.189			0.234	$\frac{15}{64}''$	0.234	$\frac{15}{64}''$	0.228	No. 1
	20	0.037	0.209	0.185	No. 13	20	0.031	0.189								
	18	0.050	0.209	0.191	No. 11	18	0.040	0.189								
	16	0.062	.....	0.199	No. 8	16	0.050	0.199								
	14	0.078	.....	0.204	No. 6	14	0.064	.....	0.199	No. 8						
	12	0.109	.....	0.209	No. 4	12	0.080	.....	0.201	No. 7						
	$\frac{1}{8}''$	0.125	.....	0.228	No. 1	10	0.101	.....	0.204	No. 6						
	10	0.140	.....	0.228	No. 1	8	0.128	.....	0.209	No. 4						
	8	0.171	.....	0.234	$\frac{15}{64}''$	6	0.162	.....	0.213	No. 3						
	$\frac{3}{16}''$	0.187	.....	0.234	$\frac{15}{64}''$	$\frac{1}{4}''$	0.250	.....	0.221	No. 2						
	6	0.203	.....	0.234	$\frac{15}{64}''$	$\frac{3}{8}''$	0.375	.....	0.228	No. 1						

* Dimensions given for screw diameter subject to tolerances.

NOTE.—To obtain satisfactory results the holes must be neither too large nor too small. The size of the hole depends upon certain factors such as the kind of material, its degrees of hardness, its uniformity, etc. In most cases the hole sizes shown in the table above will be found suitable; but if the material into which the screws are to be driven happens to be very hard, it might be necessary to use a size larger drill, while in very soft material, a size smaller drill should be used.

Table 34.—Rod End Pins, S.A.E. Standard



The standard pins are made of commercial cold-rolled steel. The hardened pins are made of S. A. E. 1010 steel or equivalent and are cyanide hardened.

(All Dimensions in Inches)

A	Nominal diameter	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$
	Max. diameter	.186	.248	.311	.373	.436	.496
	Min. diameter	.181	.243	.306	.368	.431	.491
B	Length	$\frac{19}{32}$	$\frac{51}{64}$	$\frac{31}{32}$	$1\frac{3}{32}$	$1\frac{15}{64}$	$1\frac{25}{64}$
C	Head diameter	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$
D	Head thickness	$\frac{1}{16}$	$\frac{3}{32}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{5}{32}$
E	To hole	$\frac{31}{64}$	$\frac{43}{64}$	$\frac{13}{16}$	$\frac{15}{16}$	$1\frac{1}{16}$	$1\frac{13}{64}$
F	Drill diameter	#48 (.076)	#48 (.076)	#36 (.106)	#36 (.106)	#36 (.106)	#28 (.140)
G	Chamfer	$\frac{3}{64}$	$\frac{1}{16}$	$\frac{5}{64}$	$\frac{5}{64}$	$\frac{3}{32}$	$\frac{7}{64}$
H	Chamfer	$\frac{1}{64}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{3}{64}$	$\frac{3}{64}$
	Weight, lbs. per 1,000						

Studs

Experiments as to the depth of thread (not depth of hole) show that the tap drill can be much larger than is generally supposed and still hold the stud against stripping, even in aluminum. Tests show that a 43 per cent depth of thread in aluminum will break a $\frac{5}{16}$-inch stud before stripping, when the stud is a good fit, or, in other words, when the stud is 0.003 inch larger than the tapped hole.

The depth of the hole also has its effect, but a depth of $1\frac{1}{2}$ diameters is sufficient for most materials, unless the stud has to carry an appreciable fatigue stress. In that case, 2 diameters will be better.

The "lute" or material used on the threads in setting studs also affects the torque. White lead is frequently used with iron or steel, and oil with aluminum. One motor builder uses kerosene in the latter case.

There is a tendency toward using ground taps and chasers for stud holes and studs which are held to very close limits, as these give greater area of contact and the studs hold better. Some use a commercial tap first and finish with a ground tap. Some advocate a four-fluted tap with narrow lands for cast iron and a three-fluted tap with wider lands for steel and aluminum. Some rough tap by machine and leave 0.010 inch for a hand-finishing tap. Holes are tapped straight in almost every case, but one builder of large machinery uses a taper of $\frac{1}{8}$ inch per foot.

The chamfering of the end of studs also plays a part. Some contend that the chamfer of 90 degrees included angle throws up a burr on the first thread, which makes a stud drive hard but allows it to unscrew easily. They prefer the 60-degree included angle.

Another authority gives the following allowances for the stud end in order to ensure a tight fit in different materials:

For aluminum, actual pitch diameter plus..... 0.004–0.006 inch.
For cast iron, actual pitch diameter plus...... 0.002–0.004 inch.
For steel, actual pitch diameter plus.......... 0.001–0.003 inch.
For brass and bronze, actual pitch diameter plus 0.003–0.005 inch.

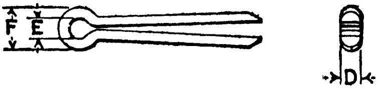


TABLE 35.—STANDARD COTTER PINS
General Motors Company
(Dimensions in Inches)

D	Nominal dia. .	$\frac{3}{64}$	$\frac{1}{16}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{7}{32}$	$\frac{1}{4}$	$\frac{5}{16}$
	Actual dia. min.	.042	.058	.086	.118	.146	.172	.202	.220	.275
	Actual dia. max.	.045	.061	.090	.122	.150	.176	.207	.225	.280
E	Inside dia., of eye..........	$\frac{1}{16}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{7}{32}$	$\frac{1}{4}$	$\frac{5}{16}$
F	Outside dia., of eye (approx.).	$\frac{7}{64}$	$\frac{5}{32}$	$\frac{7}{32}$	$\frac{9}{32}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{5}{8}$
	Drill dia.......	#52 (.0635)	#48 (.076)	#36 (.1065)	#28 (.1405)	#17 (.173)	#7 (.201)	B (.238)	$\frac{9}{32}$	$\frac{11}{32}$

Tolerance—plus or minus 0.010 inch.

COTTER PINS, S.A.E. STANDARD

Three points are used which are optional: the standard point, the double-bevel point, and the extended prong. There is no difference in the cost of pins with either of these points.

These pins are slightly smaller in diameter than the nominal diameter given, as this practice has become standard with all cotter-pin manufacturers. When pins are ordered of a certain nominal diameter, the undersize pins are furnished. Where full-diameter pins are required the purchaser must specify that these pins be "full-diameter wire." The latter, however, run from 14 to 25 per cent greater in price than the standard undersize pins.

TABLE 36.—COTTERS USED IN BOLTS OR ROD ENDS—COTTER PINS—S.A.E. STANDARDS FOR BOLTS
(Dimensions in Inches)

Bolt or Rod-End Pin Diam.	National Coarse Thread Bolts					Fine (S. A. E.)		
	Cotter Diam.	B.W.G. Gage	Cotter Length		Drill No.	Cotter Length		Drill No.
			Short	Long		Short	Long	
1/4	1/16		1/2	5/8	48	1/2	5/8	48
5/16	1/16		5/8	3/4	48	5/8	3/4	48
3/8	3/32		3/4	7/8	36	5/8	3/4	36
7/16	3/32	13	3/4	1	36	5/8	3/4	36
1/2	3/32		7/8	1 1/8	36	3/4	7/8	36
9/16	1/8		1	1 1/4	30	7/8	1 1/8	28
5/8	1/8	11	1 1/8	1 3/8	30	1	1 1/4	28
11/16			1 1/8	1 3/8	30			
3/4	1/8		1 1/4	1 1/2	28	1 1/8	1 3/8	28
7/8	1/8	11	1 3/8	1 3/4	21	1 1/4	1 1/2	28
1	1/8	8	1 5/8	2	21	1 1/2	1 3/4	28
1 1/8	11/64		1 3/4	2 1/4	11	1 5/8	2	11
1 1/4	11/64	8	2	2 1/2	11	1 3/4	2 1/4	11
1 3/8	13/64	6	2 1/4	2 3/4	2	2	2 1/2	2
1 1/2	13/64		2 1/4	3	2	2 1/4	2 3/4	2

STANDARD WOOD SCREWS

This standard is the result of cooperation between screw manufacturers and the Bureau of Standards. The increment between sizes is now 0.013 inch instead of 0.013165 inch as formerly. Several sizes have been omitted, the total number of sizes and lengths being reduced from 555 to 291. Gimlet points are standard, cone and diamond points are special. Length of screws is measured from the largest diameter of bearing surface of head to the point. Screws are threaded approximately two-thirds of their length. Diameter is measured under the head. Tolerance on diameter is from 0.004 inch plus to 0.007 inch minus. A 10 per cent variation in threads per inch is permitted. The angle of cone and flat heads is 82 degrees maximum, 80 degrees minimum. The head dimensions are now exactly the same as those of machine screws of the same size. Machine screws, however, begin at No. 2 and end at No. 12, so the wood-screw sizes are given here.

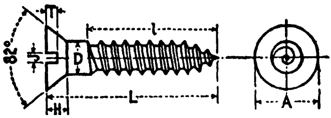


TABLE 37.—HEAD DIMENSIONS, FLAT-HEAD WOOD SCREWS

Screw Number	Threads per Inch	D	A		H		J		T	
		Diameter	Head Diameter		Height of Head		Width of Slot		Depth of Slot	
			Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
0	32	0.060	0.119	0.105	0.035	0.026	0.031	0.020	0.155	0.010
1	28	0.073	0.146	0.130	0.043	0.033	0.033	0.022	0.019	0.012
2	26	0.086	0.172	0.156	0.051	0.040	0.036	0.024	0.023	0.015
3	24	0.099	0.199	0.181	0.059	0.048	0.038	0.026	0.027	0.017
4	22	0.112	0.225	0.207	0.067	0.055	0.040	0.028	0.030	0.020
5	20	0.125	0.252	0.232	0.075	0.062	0.043	0.031	0.034	0.022
6	18	0.138	0.279	0.257	0.083	0.069	0.045	0.033	0.038	0.024
7	16	0.151	0.305	0.283	0.091	0.076	0.047	0.035	0.041	0.027
8	15	0.164	0.332	0.308	0.100	0.084	0.050	0.037	0.045	0.029
9	14	0.177	0.358	0.334	0.108	0.091	0.042	0.039	0.049	0.032
10	13	0.190	0.385	0.359	0.116	0.098	0.055	0.041	0.053	0.034
11	12	0.203	0.411	0.385	0.124	0.105	0.057	0.043	0.056	0.037
12	11	0.216	0.438	0.410	0.132	0.112	0.059	0.045	0.060	0.039
14	10	0.242	0.491	0.461	0.148	0.127	0.064	0.050	0.068	0.044
16	9	0.268	0.544	0.512	0.164	0.141	0.069	0.054	0.075	0.049
18	8	0.294	0.597	0.563	0.180	0.155	0.074	0.058	0.083	0.054
20	8	0.320	0.650	0.614	0.196	0.170	0.078	0.062	0.090	0.059
24	7	0.372	0.756	0.716	0.228	0.198	0.088	0.071	0.105	0.069

All dimensions in inches.

Formulas

Head diameter, height of head, width of slot, depth of slot, countersink angle are same as Table 1. Head angle can be 80 to 82 degrees.

CROSS-SLOTTED WOOD-SCREW HEADS

Screwheads with cross slots, known as the Phillips and made by the American Screw Company, have been standardized; these heads are shown in Tables 9 to 15 in this section. Flat-, round-, and oval-head wood screws have the same dimensions as machine screws of same sizes. Wing thickness *T* is the same in all types of heads. The upper dimension is maximum, and the lower is minimum in each case.

TABLE 38.—HEAD DIMENSIONS, ROUND-HEAD WOOD SCREWS

Screw Number	Threads per Inch	Diameter, D	Head Diameter, A		Height of Head, H		Width of Slot, J		Depth of Slot, T	
			Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
0	32	0.060	0.113	0.099	0.053	0.042	0.031	0.020	0.039	0.029
1	28	0.073	0.138	0.122	0.061	0.051	0.033	0.022	0.043	0.033
2	26	0.086	0.162	0.146	0.070	0.059	0.036	0.024	0.048	0.036
3	24	0.099	0.187	0.169	0.078	0.067	0.038	0.026	0.053	0.040
4	22	0.112	0.211	0.193	0.086	0.075	0.040	0.028	0.058	0.043
5	20	0.125	0.236	0.217	0.095	0.083	0.043	0.031	0.062	0.047
6	18	0.138	0.260	0.240	0.103	0.091	0.045	0.033	0.067	0.050
7	16	0.151	0.285	0.264	0.111	0.099	0.047	0.035	0.072	0.053
8	15	0.164	0.309	0.287	0.119	0.107	0.050	0.037	0.076	0.057
9	14	0.177	0.334	0.311	0.128	0.115	0.052	0.039	0.081	0.060
10	13	0.190	0.359	0.334	0.136	0.124	0.055	0.041	0.086	0.064
11	12	0.203	0.383	0.358	0.144	0.132	0.057	0.043	0.090	0.067
12	11	0.216	0.408	0.382	0.152	0.140	0.059	0.045	0.095	0.071
14	10	0.242	0.457	0.429	0.169	0.156	0.064	0.050	0.105	0.078
16	9	0.268	0.506	0.476	0.185	0.172	0.069	0.054	0.114	0.085
18	8	0.294	0.555	0.523	0.202	0.188	0.074	0.058	0.123	0.092
20	8	0.320	0.604	0.570	0.219	0.205	0.078	0.062	0.133	0.099
24	7	0.372	0.702	0.664	0.252	0.237	0.088	0.071	0.152	0.113

All dimensions in inches.
Tolerance in diameter D = +0.004 to −0.007 inch.

Formulas

Shape of head; semielliptical.

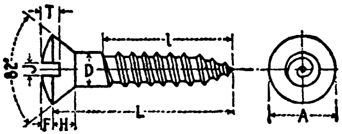


TABLE 39.—HEAD DIMENSIONS, OVAL-HEAD WOOD SCREWS

Screw Number	Threads per Inch	D	A		H		J		T		F		F + H	
		Diameter	Head Diameter		Height of Head		Width of Slot		Depth of Slot		Height of Oval		Total Height of Head	
			Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
0	32	0.060	0.119	0.105	0.035	0.026	0.031	0.020	0.030	0.025	0.021	0.015	0.056	0.041
1	28	0.073	0.146	0.130	0.043	0.033	0.033	0.022	0.038	0.031	0.025	0.019	0.068	0.052
2	26	0.086	0.172	0.156	0.051	0.040	0.036	0.024	0.045	0.037	0.029	0.022	0.079	0.062
3	24	0.099	0.199	0.181	0.059	0.048	0.038	0.026	0.052	0.043	0.033	0.026	0.092	0.074
4	22	0.112	0.225	0.207	0.067	0.055	0.040	0.028	0.059	0.049	0.037	0.029	0.104	0.084
5	20	0.125	0.252	0.232	0.075	0.062	0.043	0.031	0.067	0.055	0.041	0.033	0.116	0.095
6	18	0.138	0.279	0.257	0.083	0.069	0.045	0.033	0.074	0.060	0.045	0.036	0.128	0.105
7	16	0.151	0.305	0.283	0.091	0.076	0.047	0.035	0.081	0.066	0.049	0.039	0.140	0.115
8	15	0.164	0.332	0.308	0.100	0.084	0.050	0.037	0.088	0.072	0.053	0.043	0.153	0.127
9	14	0.177	0.358	0.334	0.108	0.091	0.052	0.039	0.095	0.078	0.057	0.046	0.165	0.137
10	13	0.190	0.385	0.359	0.116	0.098	0.055	0.041	0.103	0.084	0.061	0.050	0.177	0.148
11	12	0.203	0.411	0.385	0.124	0.105	0.057	0.043	0.110	0.090	0.065	0.053	0.189	0.158
12	11	0.216	0.438	0.410	0.132	0.112	0.059	0.045	0.117	0.096	0.069	0.057	0.201	0.169

14	10	0.242	0.491	0.461	0.148	0.127	0.064	0.050	0.132	0.108	0.077	0.064	0.225	0.191
16	9	0.268	0.544	0.512	0.164	0.141	0.069	0.054	0.146	0.120	0.084	0.071	0.248	0.212
18	8	0.294	0.597	0.563	0.180	0.155	0.074	0.058	0.160	0.132	0.092	0.088	0.272	0.233
20	8	0.320	0.650	0.614	0.196	0.170	0.078	0.062	0.175	0.144	0.100	0.085	0.296	0.255
24	7	0.372	0.756	0.716	0.228	0.198	0.088	0.071	0.204	0.168	0.116	0.099	0.344	0.297

All dimensions in inches.
Tolerance in diameter D = +0.004 to −0.007 inch.

Formulas

Head diameter, height of head (countersink), width of slot, total height of head, depth of slot, height of oval, countersink angle are same as Table 3.

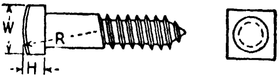
TABLE 40.—LENGTH TOLERANCES OF ROUND-HEAD WOOD SCREWS

SCREW NUMBER	TOLERANCE, MINUS, IN INCHES
0	0.06
1	0.07
2	0.08
3	0.08
4	0.09
5	0.10
6	0.10
7	0.11
8	0.12
9	0.13
10	0.13
11	0.14
12	0.15
14	0.16
16	0.18
18	0.20
20	0.22
24	0.27

TABLE 41.—LENGTHS OF FLAT- AND OVAL-HEAD WOOD SCREWS

Nominal	Maximum	Minimum
1/4	0.250	0.22
3/8	0.375	0.34
1/2	0.500	0.46
5/8	0.625	0.59
3/4	0.750	0.71
7/8	0.875	0.83
1	1.000	0.96
1 1/4	1.250	1.20
1 1/2	1.500	1.45
1 3/4	1.750	1.69
2	2.000	1.94
2 1/4	2.250	2.19
2 1/2	2.500	2.43
2 3/4	2.750	2.68
3	3.000	2.92
3 1/2	3.500	3.42
4	4.000	3.91
4 1/2	4.500	4.40
5	5.000	4.89

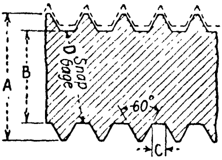
All dimensions in inches.



COACH OR LAG SCREWS
(Dimensions in Inches)

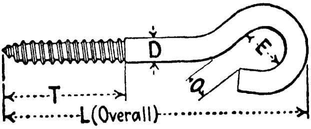
Nom. Diam.	*W*	*H*	*R*	Threads per Inch	Threads per Inch on Pt.	Longest Pointed	Shortest Pointed
1/4	3/8	3/16	7/8	10	8 1/3	10 1/2	1
5/16	15/32	15/64	7/8	9	7 1/8	10 1/2	1 1/4
3/8	9/16	9/32	1	7	6 1/2	10 1/2	1 1/2
7/16	21/32	21/64	1	7	6 1/2	10 1/2	1 1/2
1/2	3/4	3/8	1 1/4	6	5 1/8	17	1 1/2
9/16	27/32	27/64	1 1/4	5 1/2	5 1/8	17	1 3/4
5/8	15/16	15/32	1 1/2	5	4 1/3	17	2
3/4	1 1/8	9/16	2	4 1/2	3.9	17	2 1/2
7/8	1 5/16	21/32	*	4	3 1/2	17	3 1/2
1	1 1/2	3/4	*	3 1/2	3	17	4 1/2

* Crown same as square-head machine bolt. Length of thread varies from about 3/4, the length on short scrows, to 1/2, the length on long bolts (Buffalo Bolt Co.).



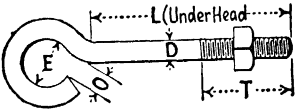
COACH SCREW THREADS
(Dimensions in Inches)

Nom. Diam.	Threads per Inch	*A*		*B*	*C*	*D*
		Min.	Max.			
1/4	10	0.233	0.236	0.185	0.0500	0.191
5/16	9	0.294	0.298	0.231	0.0502	0.250
3/8	7	0.356	0.360	0.278	0.0690	0.286
7/16	7	0.418	0.423	0.324	0.0594	0.333
1/2	6	0.479	0.484	0.370	0.0702	0.379
9/16	5 1/2	0.539	0.554	0.416	0.0756	0.426
5/8	5	0.601	0.616	0.463	0.0815	0.475
3/4	4 1/2	0.724	0.739	0.555	0.0820	0.566
7/8	4	0.849	0.864	0.647	0.0875	0.658
1	3 1/2	0.974	0.989	0.740	0.0998	0.754



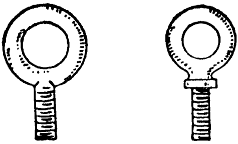
CEILING HOOKS
(Dimensions in Inches)

Trade Size	Diameter *D*	Length *L*	Length Threaded *T*	Diameter of Eye *E*	Width of Opening *O*
$\frac{1}{4} \times 3$	$\frac{1}{4}$	3	$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{5}{16}$
$\frac{1}{4} \times 3\frac{1}{2}$	$\frac{1}{4}$	$3\frac{1}{2}$	$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{5}{16}$
$\frac{5}{16} \times 3$	$\frac{5}{16}$	3	1	$\frac{3}{4}$	$\frac{11}{32}$
$\frac{5}{16} \times 3\frac{1}{2}$	$\frac{5}{16}$	$3\frac{1}{2}$	$1\frac{3}{4}$	$\frac{3}{4}$	$\frac{11}{32}$
$\frac{5}{16} \times 4$	$\frac{5}{16}$	4	$1\frac{3}{4}$	$\frac{3}{4}$	$\frac{11}{32}$
$\frac{3}{8} \times 4\frac{1}{2}$	$\frac{3}{8}$	$4\frac{1}{2}$	$2\frac{1}{4}$	$\frac{3}{4}$	$\frac{11}{32}$



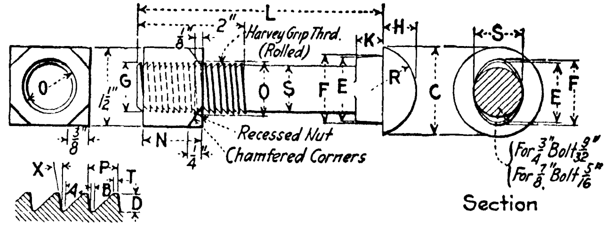
OPEN-EYE EYE BOLTS
(Dimensions in Inches)

Trade Size	Diameter *D*	Length *L*	Length Threaded *T*	Diameter of Eye *E*	Width of Opening *O*
$\frac{1}{4} \times 1\frac{1}{2}$	$\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{1}{4}$	$\frac{3}{4}$	$\frac{9}{64}$
$\frac{1}{4} \times 2$	$\frac{1}{4}$	2	$1\frac{1}{4}$	$\frac{3}{4}$	$\frac{9}{64}$
$\frac{1}{4} \times 2\frac{1}{2}$	$\frac{1}{4}$	$2\frac{1}{2}$	$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{9}{64}$
$\frac{1}{4} \times 3$	$\frac{1}{4}$	3	$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{9}{64}$
$\frac{1}{4} \times 3\frac{1}{2}$	$\frac{1}{4}$	$3\frac{1}{2}$	$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{9}{64}$
$\frac{1}{4} \times 4$	$\frac{1}{4}$	4	$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{9}{64}$
$\frac{5}{16} \times 1\frac{1}{2}$	$\frac{5}{16}$	$1\frac{1}{2}$	$1\frac{1}{4}$	$\frac{3}{4}$	$\frac{5}{16}$
$\frac{5}{16} \times 2\frac{1}{2}$	$\frac{5}{16}$	$2\frac{1}{2}$	$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{5}{16}$
$\frac{5}{16} \times 3$	$\frac{5}{16}$	3	$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{5}{16}$
$\frac{5}{16} \times 3\frac{1}{2}$	$\frac{5}{16}$	$3\frac{1}{2}$	$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{5}{16}$
$\frac{3}{8} \times 1\frac{1}{2}$	$\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{1}{4}$	$\frac{3}{4}$	$\frac{11}{32}$
$\frac{3}{8} \times 2\frac{1}{2}$	$\frac{3}{8}$	$2\frac{1}{2}$	$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{11}{32}$
$\frac{3}{8} \times 3$	$\frac{3}{8}$	3	$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{11}{32}$
$\frac{3}{8} \times 3\frac{1}{2}$	$\frac{3}{8}$	$3\frac{1}{2}$	$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{11}{32}$



Dimensions of Williams "Vulcan" Plain and Shoulder Eye Bolts

PLAIN								SHOULDER				
Shank			Diameter Eye		Capacity, Net Tons			Shank			Diameter Eye	
Diameter	Standard Length under Eye	Maximum Length in Stock	Inside	Outside	Safe Working Load	Average Load at Elastic Limit	Approximate Breaking Strain	Diameter	Standard Length under Shoulder	Maximum Length in Stock	Inside	Outside
3/8	1 1/4	4 1/2	1	1 21/32	0.7	1.4	3	1/4	1	3	3/4	1 3/16
7/16	1 3/8	4 1/2	1 3/32	1 27/32	1	2	4	5/16	1 1/8	4	7/8	1 7/16
1/2	1 1/2	4 1/2	1 3/16	2 1/16	1.3	2.5	5	3/8	1 1/4	4 1/2	1	1 21/32
9/16	1 5/8	4 1/2	1 9/32	2 9/32	1.5	3	6	7/16	1 3/8	4 1/2	1 3/32	1 27/32
5/8	1 3/4	4 1/2	1 3/8	2 1/2	2	4	8	1/2	1 1/2	4 1/2	1 3/16	2 1/16
3/4	2	5	1 1/2	2 13/16	3	6	12	9/16	1 5/8	4 1/2	1 9/32	2 9/32
7/8	2 1/4	5	1 11/16	3 1/4	3.5	7	16	5/8	1 3/4	4 1/2	1 3/8	2 1/2
1	2 1/2	5	1 13/16	3 9/16	4	8	20	3/4	2	5	1 1/2	2 13/16
1 1/8	2 3/4	5	2	4	5	10	23	7/8	2 1/4	5	1 11/16	3 1/4
1 1/4	3	6	2 3/16	4 7/16	7.5	15	33	1	2 1/2	5	1 13/16	3 9/16
1 3/8	3 1/2	6	2 1/2	5 3/16	9	18	42	1 1/8	2 3/4	5	2	4
1 1/2	3 3/4	6	2 7/8	6 1/16	11	21	53	1 1/4	3	6	2 3/16	4 7/16
2	4	6	3 1/4	6 7/8	13	25	68	1 1/2	3 1/2	6	2 1/2	5 3/16
2 1/2	5	6	4	8 9/16	16	32	85	1 3/4	3 3/4	6	2 7/8	6 1/16
								2	4	6	3 1/4	6 7/8



Harvey Grip Bolt Thread Enlarged

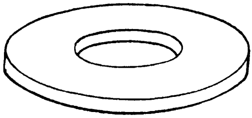
HARVEY GRIP BOLT THREAD ENLARGED

Size of bolt	Dimensions of thread					
	A	X	P	D	B	T
3/4"	45°	Max. 10°	.1000"	Min. .065"	.0118"	.0118"
7/8"	45°	Max. 10°	.1111"	Min. .072"	.0132"	.0132"

Weight of rail	Dimensions											Threads per inch
	S	L	C	H	F	G	K	N	N	O	R	
	3/4"		1 5/16"	17/32"	1 1/32"	1 1/16"	13/16"	7/16"	1"	7/8"	43/64"	10
	7/8"		1 1/2"	5/8"	1 3/16"	1 7/32"	15/16"	1/2"	1 1/8"	1"	3/4"	9
	7/8"		1 1/2"	5/8"	1 1/16"	1 7/32"	15/16"	1/2"	1 1/8"	1"	3/4"	9

RIVETING WASHERS

Size of Rivet	Size of Hole	Outside Diameter	Thickness Wire Gage	Size of Rivet	Size of Hole	Outside Diameter	Thickness Wire Gage
7 (.180)	3/16	1/2	18	3/8	13/32	1 1/4	12
6 (.203)	7/32	9/16	18	7/16	15/32	1	14
5 (.220)	15/64	5/8	18	7/16	15/32	1 1/4	12
1/4	17/64	5/8	16	1/2	17/32	1 1/8	12
1/4	17/64	3/4	16	1/2	17/32	1 1/4	12
5/16	11/32	3/4	14	1/2	17/32	1 1/2	11
5/16	11/32	7/8	14	5/8	21/32	1 1/2	11
3/8	13/32	7/8	14	5/8	21/32	1 3/4	10
3/8	13/32	1	14				



Plain Washers U. S. Standard (Dimensions in Inches)

Size of Bolt	Size of Hole	Outside Diameter	Thickness Wire Gage No.	Weight per 1,000, in Pounds
3/16	1/4	9/16	18 (3/64)	2.53
1/4	5/16	3/4	16 (1/16)	6.40
5/16	3/8	7/8	16 (1/16)	8.80
3/8	7/16	1	14 (5/64)	14.7
7/16	1/2	1 1/4	14 (5/64)	21
1/2	9/16	1 3/8	12 (3/32)	38.4
9/16	5/8	1 1/2	12 (3/32)	44 4
5/8	11/16	1 3/4	10 (1/8)	77
3/4	13/16	2	10 (1/8)	111
7/8	15/16	2 1/4	9 (5/32)	153
1	1 1/16	2 1/2	9 (5/32)	176
1 1/8	1 1/4	2 3/4	9 (5/32)	
1 1/4	1 3/8	3	9 (5/32)	
1 3/8	1 1/2	3 1/4	8 (11/64)	
1 1/2	1 5/8	3 1/2	8 (11/64)	
1 5/8	1 3/4	3 3/4	8 (11/64)	
1 3/4	1 7/8	4	8 (11/64)	
1 7/8	2	4 1/4	8 (11/64)	
2	2 1/8	4 1/2	8 (11/64)	
2 1/4	2 3/8	4 3/4	6 (3/16)	
2 1/2	2 5/8	5	5 (7/32)	

Plain Washers S. A. E. Standard (Dimensions in Inches)

Size of Bolt	Size of Hole	Outside Diameter	Thickness Wire Gage No.
6	5/32	3/8	3/64
8	3/16	7/16	3/64
10	7/32	1/2	1/16
1/4	9/32	5/8	1/16
5/16	11/32	11/16	1/16
3/8	13/32	13/16	1/16
7/16	15/32	15/16	1/16
1/2	17/32	1 1/16	3/32
9/16	19/32	1 3/16	3/32
5/8	21/32	1 5/16	3/32
3/4	13/16	1 1/2	1/8
7/8	15/16	1 3/4	1/8

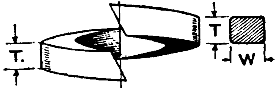
Narrow-gage Washers (Dimensions in Inches)

Size of Bolt	Size of Hole	Outside Diameter	Thickness Wire Gage No.
1/4	5/16	5/8	16 (1/16)
5/16	3/8	3/4	16 (1/16)
3/8	7/16	7/8	16 (1/16)
7/16	1/2	1 1/8	14 (5/64)
1/2	9/16	1 1/4	12 (3/32)
9/16	5/8	1 3/8	12 (3/32)
5/8	11/16	1 1/2	10 (1/8)
3/4	13/16	1 3/4	10 (1/8)
7/8	15/16	2	9 (5/32)
1	1 1/16	2 1/4	9 (5/32)
1 1/8	1 1/4	2 1/2	9 (5/32)
1 1/4	1 3/8	2 3/4	9 (5/32)
1 3/8	1 1/2	3	8 (11/64)
1 1/2	1 5/8	3 1/4	8 (11/64)

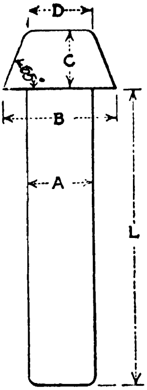
Steel No. 1010. Tolerance plus or minus 0.010.

RECOMMENDED KANTLINK SPRING WASHERS

Screw and Bolt Size		Standard Tolerances for Actual Inside Diameter of Washer		For Use with Wrench-Head Bolts, Nuts, and Screws			For Use with Slotted Head Screws				Nuts for Machine Screws and Stove Bolts Series *M*	Socket-Head Capscrews Series *N*
				All Regular Hexagon and Square Bolt Heads and Nuts Series *F*	Capscrews		Capscrews		Machine Screws			
Nominal	Actual	Maximum	Minimum		Hexagon Head Series *G*	Collar Head Series *H*	Button Head Series *I*	Fillister Head and Hexagon Socket Series *J*	Round Head Series *K*	Fillister Head Series *L*		
				Section Width and Thickness								
No. 2	0.086	0.098	0.088						1/32 × 0.022	0.022 × 0.022		
No. 3	0.099	0.111	0.101						1/32 × 1/32	1/32 × 0.022		
No. 4	0.112	0.124	0.114						1/32 × 1/32	1/32 × 0.022		0.022 × 0.022
No. 5	0.125	0.138	0.127						3/64 × 1/32	1/32 × 1/32	3/32 × 3/64	0.022 × 0.022
No. 6	0.138	0.151	0.140						3/64 × 1/32	1/32 × 1/32	3/32 × 3/64	1/32 × 1/32
No. 8	0.164	0.178	0.166						3/64 × 3/64	3/64 × 1/32	7/64 × 1/16	3/64 × 3/64
No. 10	0.190	0.206	0.192						1/16 × 3/64	1/16 × 1/32	7/64 × 1/16	3/64 × 3/64
No. 12	0.216	0.235	0.216						3/32 × 1/16	5/64 × 1/16	1/8 × 1/16	3/64 × 5/64
1/4	0.250	0.269	0.254	9/64 × 5/64	1/8 × 1/16	3/32 × 1/16	3/32 × 1/16	1/16 × 1/16	3/32 × 1/16	3/32 × 3/64	9/64 × 5/64	3/64 × 5/64
5/16	0.313	0.334	0.317	5/32 × 3/32	9/64 × 5/64	3/32 × 5/64	1/8 × 5/64	1/16 × 1/16	1/8 × 5/64	1/8 × 1/16	5/32 × 3/32	3/64 × 5/64
3/8	0.375	0.400	0.380	11/64 × 7/64	5/32 × 3/32	1/8 × 3/32	1/8 × 3/32	3/32 × 5/64	9/64 × 3/32	1/8 × 5/64	11/64 × 7/64	5/64 × 1/8
7/16	0.438	0.467	0.443	13/64 × 1/8	11/64 × 7/64	1/8 × 1/8	5/32 × 1/8	3/32 × 5/64	5/32 × 7/64	9/64 × 5/64		5/64 × 1/8
1/2	0.500	0.533	0.506	7/32 × 9/64	3/16 × 1/8	5/32 × 1/8	5/32 × 1/8	1/8 × 3/32	11/64 × 1/8	11/64 × 3/32		7/64 × 11/64
9/16	0.563	0.596	0.569	1/4 × 3/16	13/64 × 1/8	3/16 × 5/32	3/16 × 5/32	1/8 × 3/32				
5/8	0.625	0.662	0.633	9/32 × 11/64	7/32 × 5/32	3/16 × 5/32	3/16 × 5/32	1/8 × 1/8				7/64 × 11/64
3/4	0.750	0.791	0.761	5/16 × 13/64	1/4 × 3/16	1/4 × 3/16	1/4 × 3/16	1/8 × 1/8				7/64 × 3/16
7/8	0.875	0.922	0.891	11/32 × 1/4	5/16 × 7/32			1/8 × 1/8				7/64 × 3/16
1	1.000	1.047	1.016	13/32 × 9/32	5/16 × 1/4			5/32 × 5/32				1/8 × 13/64
1 1/8	1.125	1.172	1.141	7/16 × 5/16	3/8 × 9/32			3/16 × 3/16				5/32 × 5/16
1 1/4	1.250	1.313	1.271	1/2 × 5/16	7/16 × 5/16			1/4 × 1/4				7/32 × 5/16
1 3/8	1.375	1.447	1.385	1/2 × 3/8	1/2 × 5/16							
1 1/2	1.500	1.572	1.510	1/2 × 3/8	1/2 × 5/16			1/4 × 1/4				7/32 × 5/16

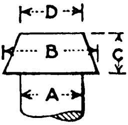


U. S. NAVY BOILER RIVETS

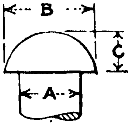


A	B	C	D	Weight of 10 heads	Weight per inch of shank L
1/2	15/16	7/16	1/2	.531	.0556
9/16	1	1/2	9/16	.713	.0704
5/8	1 1/8	9/16	5/8	1.007	.0869
11/16	1 1/4	5/8	11/16	1.372	.1052
3/4	1 5/16	5/8	3/4	1.551	.1251
13/16	1 7/16	11/16	13/16	2.033	.1470
7/8	1 1/2	11/16	7/8	2.258	.1703
15/16	1 5/8	3/4	15/16	2.871	.1956
1	1 3/4	13/16	1	3.584	.2225
1 1/16	1 13/16	13/16	1 1/16	3.910	.2512
1 1/8	1 15/16	7/8	1 1/8	4.761	.2816
1 3/16	2	7/8	1 3/16	5.170	.3137
1 1/4	2 1/8	15/16	1 1/4	6.215	.3477
1 5/16	2 1/4	1	1 5/16	7.391	.3833
1 3/8	2 3/8	1 1/16	1 3/8	8.490	.4207
1 7/16	2 1/2	1 1/8	1 7/16	9.941	.4599
1 1/2	2 5/8	1 3/16	1 1/2	11.507	.5006
1 9/16	2 3/4	1 1/4	1 9/16	13.242	.5433
1 5/8	2 7/8	1 5/16	1 5/8	15.146	.5876
1 11/16	3	1 3/8	1 11/16	17.300	.6336
1 3/4	3 1/8	1 7/16	1 3/4	19.485	.6815

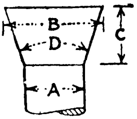
U. S. NAVY HULL AND TANK RIVET HEADS



PAN-HEAD



BUTTON



COUNTERSUNK

Pan-head				Button			Countersunk			
A	B	C	D	A	B	C	A	B	C	D
1/4	7/16	3/16	1/4	1/4	7/16	3/16	1/4	3/8	3/32	60
3/8	5/8	5/16	3/8	3/8	5/8	5/16	3/8	5/8	7/32	60
1/2	13/16	3/8	1/2	1/2	13/16	3/8	1/2	13/16	1/4	60
5/8	1	7/16	5/8	5/8	1	7/16	5/8	1 1/16	3/8	60
3/4	1 3/16	1/2	3/4	3/4	1 3/16	1/2	3/4	1 5/32	1/2	45
7/8	1 5/16	9/16	7/8	7/8	1 5/16	9/16	7/8	1 7/16	11/16	45
1	1 1/2	5/8	1	1	1 1/2	5/8	1	1 5/8	15/16	37
1 1/8	1 5/8	11/16	1 1/8	1 1/8	1 5/8	11/16	1 1/8	1 3/4	13/16	37
1 1/4	1 13/16	3/4	1 1/4	1 1/4	1 13/16	3/4	1 1/4	1 29/32	1	37

LENGTH OF ROUND HEAD RIVETS FOR DIFFERENT THICKNESSES OF METAL

To find the required length of a rivet when thickness of metal between rivet heads is given, assuming the rivet hole to be 1/16 inch larger than the rivet before it is heated, refer to the table below. Grip in inches means thickness of metal between rivet heads.

Grip in Inches.	Diameter in Inches				
	1/2	5/8	3/4	7/8	1
	Length in Inches.				
1/2	1 1/2	1 3/4	1 7/8	2	2 1/8
5/8	1 5/8	1 7/8	2	2 1/8	2 1/4
3/4	1 3/4	2	2 1/8	2 1/4	2 3/8
7/8	1 7/8	2 1/8	2 1/4	2 3/8	2 1/2
1	2	2 1/4	2 3/8	2 1/2	2 5/8
1 1/8	2 1/8	2 3/8	2 1/2	2 5/8	2 3/4
1 1/4	2 1/4	2 1/2	2 5/8	2 3/4	2 7/8
1 3/8	2 3/8	2 5/8	2 3/4	2 7/8	3
1 1/2	2 5/8	2 7/8	3	3 1/8	3 1/4
1 5/8	2 3/4	3	3 1/8	3 1/4	3 3/8
1 3/4	2 7/8	3 1/8	3 1/4	3 3/8	3 1/2
1 7/8	3	3 1/4	3 3/8	3 1/2	3 5/8
2	3 1/8	3 3/8	3 1/2	3 5/8	3 3/4
2 1/8	3 1/4	3 1/2	3 5/8	3 3/4	3 7/8
2 1/4	3 3/8	3 5/8	3 3/4	3 7/8	4
2 3/8	3 1/2	3 3/4	3 7/8	4	4 1/8
2 1/2	3 5/8	3 7/8	4	4 1/8	4 1/4
2 5/8	3 3/4	4	4 1/8	4 1/4	4 3/8
2 3/4	3 7/8	4 1/8	4 1/4	4 3/8	4 1/2
2 7/8	4	4 1/4	4 3/8	4 1/2	4 5/8
3	4 1/4	4 1/2	4 5/8	4 3/4	4 7/8
3 1/8	4 3/8	4 5/8	4 3/4	4 7/8	5
3 1/4	4 1/2	4 3/4	4 7/8	5	5 1/8
3 3/8	4 5/8	4 7/8	5	5 1/8	5 1/4
3 1/2	4 3/4	5	5 1/8	5 1/4	5 3/8
3 5/8	4 7/8	5 1/8	5 1/4	5 3/8	5 1/2
3 3/4	5	5 1/4	5 3/8	5 1/2	5 5/8
3 7/8	5 1/8	5 3/8	5 1/2	5 5/8	5 3/4
4	5 1/4	5 1/2	5 5/8	5 3/4	5 7/8
4 1/4	5 1/2	5 3/4	5 7/8	6	6 1/8
4 1/2	5 3/4	6	6 1/4	6 3/8	6 1/2
4 3/4	6 1/8	6 3/8	6 1/2	6 5/8	6 3/4
5	6 3/8	6 5/8	6 3/4	6 7/8	7

STANDARD RIVET SET AND HOLD-ON

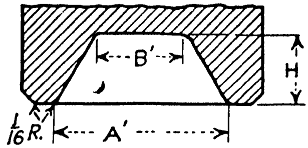


TABLE 42.—CONE HEAD
Manufactured Head after Driving and Driven Head also Hold-On (Dolly Bar) and Rivet Set Impressions

Body Diameter of Rivet D	Manufactured Head after Driving and Driven Head			Hold-On (Dolly Bar) and Rivet Set		
	A	B	H	A'	B'	H'
½ 0.500	0.092	0.469	0.406	0.891	0.469	0.391
⅝ 0.625	0.141	0.594	0.516	1.109	0.594	0.484
¾ 0.750	0.375	0.703	0.625	1.328	0.703	0.578
⅞ 0.875	0.594	0.828	0.719	1.547	0.828	0.688
1 1.000	1.828	0.938	0.828	1.781	0.938	0 781
1⅛ 1.125	2.063	1.063	0.938	2.016	1.063	0.875
1¼ 1.250	2.281	1.172	1.031	2.219	1.172	0.969
1⅜ 1.375	2.516	1.297	1.141	2.438	1.297	1.078
1½ 1.500	2.734	1.406	1.250	2.672	1.406	1.172
1⅝ 1.625	2.969	1.531	1.344	2.891	1.531	1.266
1¾ 1.750	3.203	1.641	1.453	3.109	1.641	1.375

All dimensions given in inches.
Proportions of manufactured head after driving and driven head:

$$A = 1.827D; \quad B = 0.938D; \quad H = 0.828D$$

Proportions of hold-on (dolly bar) and rivet set impressions:

$$A' = 1.781D; \quad B' = B = 0.938D; \quad H' = 0.781D$$

Dimensions have been adjusted to the nearest common fractions.

TABLE 43.—PAN HEAD

Manufactured Head after Driving and Driven Head, also Hold-On (Dolly Bar) and Rivet Set Impressions

Body Diameter of Rivet D		Manufactured Head after Driving and Driven Head			Hold-On (Dolly Bar) and Rivet Set		
		A	B	H	A'	B'	H'
1/2	0.500	0.922	0.500	0.328	0.891	0.500	0.297
5/8	0.625	1.141	0.625	0.406	1.109	0.625	0.375
3/4	0.750	1.375	0.750	0.484	1.328	0.750	0.453
7/8	0.875	1.594	0.875	0.578	1.547	0.875	0.531
1	1.000	1.828	1.000	0.656	1.781	1.000	0.609
1 1/8	1.125	2.063	1.125	0.734	2.016	1.125	0.688
1 1/4	1.250	2.281	1.250	0.813	2.219	1.250	0.766
1 3/8	1.375	2.516	1.375	0.906	2.438	1.375	0.844
1 1/2	1.500	2.734	1.500	0.984	2.672	1.500	0.906
1 5/8	1.625	2.969	1.625	1.063	2.891	1.625	0.984
1 3/4	1.750	3.203	1.750	1.141	3.109	1.750	1.063

All dimensions given in inches.

Proportions of manufactured head after driving and driven head:

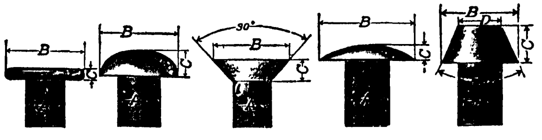
$$A = 1.827D; \quad B = D; \quad H = 0.656D$$

Proportions of hold-on (dolly bar) and rivet set impressions:

$$A' = 1.781D; \quad B' = D; \quad H' = 0.609D$$

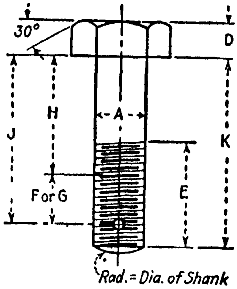
Dimensions have been adjusted to the nearest common fractions.

STANDARD HEADS ON CLARK RIVETS



Flat Head **Button Head** **Countersunk Head** **Truss Head** **Cone Head**

Flat Head			Button Head		Countersunk Head		Truss Head		Cone Head		
A	B	C	B	C	B	C	B	C	B	C	D
3/32	0.190	0.032	0.166	0.071	0.176	0.040	0.238	0.032	0.164	0.083	0.089
1/8	0.250	0.042	0.219	0.094	0.231	0.053	0.313	0.042	0.219	0.109	0.117
5/32	0.312	0.052	0.273	0.117	0.289	0.066	0.390	0.052	0.273	0.137	0.146
3/16	0.374	0.062	0.327	0.140	0.346	0.079	0.468	0.062	0.328	0.164	0.175
7/32	0.440	0.073	0.385	0.165	0.407	0.094	0.550	0.073	0.383	0.193	0.206
1/4	0.500	0.083	0.438	0.188	0.463	0.106	0.625	0.083	0.438	0.219	0.234
9/32	0.562	0.094	0.492	0.211	0.520	0.119	0.703	0.094	0.492	0.246	0.263
5/16	0.624	0.104	0.546	0.234	0.577	0.133	0.780	0.104	0.546	0.273	0.293
11/32	0.680	0.114	0.600	0.257	0.635	0.146	0.858	0.114	0.600	0.300	0.322
3/8	0.750	0.125	0.656	0.281	0.694	0.159	0.938	0.125	0.656	0.328	0.352
7/16	0.874	0.146	0.765	0.328	0.808	0.186	1.093	0.146	0.765	0.382	0.410



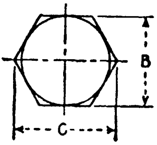


FIG. 2

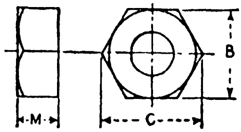


FIG. 3

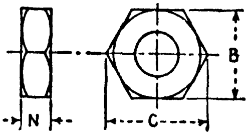


FIG. 4

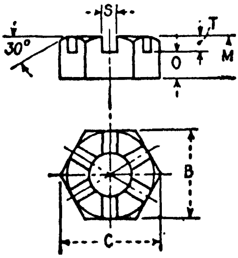


FIG. 5

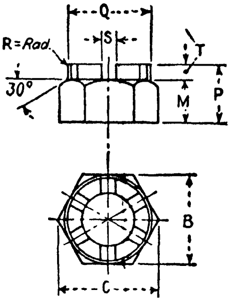


FIG. 6

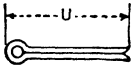


FIG. 7

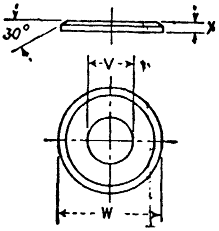


FIG. 8

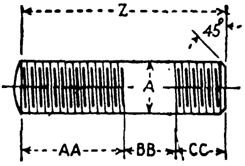


FIG. 9

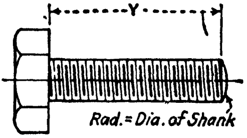


FIG. 10

(Permission British Engineering Standards Association.)

Reference cuts for Tables of British Standards, page 712.

BRITISH ENGINEERING STANDARDS ASSOCIATION

British Standard Fine (B.S.F.) Bright Hexagon Bolts, Nuts, Set Screws, Split Pins, Washers and Studs

Sizes $\frac{7}{32}$- to 2-inch diameter
(All Dimensions in Inches) (See Page 711)

Nominal size	A	$\frac{7}{32}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$
Minus tolerance in decimals		(—0.0035)	(—0.0035)	(—0.0035)	(—0.0035)	(—0.0040)	(—0.0040)	(—0.0400)	(—0.0060)
Number of threads per inch		28	26	22	20	18	16	16	14
Width across flats:									
Minimum	B	0.410	0.440	0.520	0.595	0.705	0.815	0.915	1.002
Maximum		0.413	0.445	0.525	0.600	0.710	0.820	0.920	1.010
Approximate width across corners	C	0.48	0.51	0.61	0.69	0.82	0.95	1.06	1.17
B.S.F. BOLTS									
Thickness of bolt head:									
Minimum	D	0.15	0.18	0.21	0.26	0.32	0.37	0.43	0.48
Maximum		0.16	0.19	0.22	0.27	0.33	0.38	0.44	0.49
Minimum length of thread	E	0.437	0.500	0.625	0.750	0.875	1.000	1.125	1.250
When using slotted nut	F	0.14	0.17	0.20	0.27	0.31	0.37	0.41	0.47
When using castle nut	G	0.21	0.24	0.30	0.36	0.45	0.51	0.59	0.66
Drill for split pin hole	L	0.052	0.052	0.070	0.070	0.104	0.104	0.136	0.136
B.S.F. NUTS									
Thickness of nut:									
Minimum	M	0.161	0.190	0.240	0.302	0.365	0.427	0.490	0.552
Maximum		0.171	0.200	0.250	0.312	0.375	0.475	0.500	0.562

B.S.F. LOCK NUTS									
Thickness of lock nut:									
Minimum	N	0.104	0.123	0.156	0.198	0.240	0.281	0.323	0.365
Maximum	N	0.114	0.133	0.166	0.208	0.250	0.291	0.333	0.375
B.S.F. SLOTTED NUTS									
Thickness of slotted nut:									
Minimum	M	0.161	0.190	0.240	0.302	0.365	0.427	0.490	0.552
Maximum	M	0.171	0.200	0.250	0.312	0.375	0.437	0.500	0.562
Face of nut to bottom of slot:									
Minimum	O	0.091	0.120	0.146	0.208	0.225	0.287	0.303	0.365
Maximum	O	0.101	0.130	0.156	0.218	0.235	0.297	0.313	0.375
Approximate width of slot	S	0.062	0.062	0.084	0.084	0.125	0.125	0.165	0.165
Approximate depth of slot	T	0.070	0.070	0.094	0.094	0.140	0.140	0.187	0.187
B.S.F. CASTLE NUTS									
Thickness of hexagon and from face of nut to bottom of slot:									
Minimum	M	0.161	0.190	0.240	0.302	0.365	0.427	0.490	0.552
Maximum	M	0.171	0.200	0.250	0.312	0.375	0.437	0.500	0.562
Thickness of castle nut:									
Minimum	P	0.231	0.260	0.334	0.396	0.505	0.567	0.677	0.739
Maximum	P	0.241	0.270	0.344	0.406	0.515	0.577	0.687	0.749
Diameter of castellated portion:									
Minimum	Q	0.395	0.425	0.500	0.575	0.685	0.795	0.895	0.985
Maximum	Q	0.400	0.430	0.510	0.585	0.695	0.805	0.905	0.995
Approximate width of slot	S	0.062	0.062	0.084	0.084	0.125	0.125	0.165	0.165
Approximate depth of slot	T	0.070	0.070	0.094	0.094	0.140	0.140	0.187	0.187
Radius on castellated portion	R	0.04	0.04	0.05	0.05	0.06	0.06	0.06	0.07
B.S.F. SPLIT PINS									
Diameter and overall length of split pin	U	$\frac{3}{64} \times \frac{5}{8}$	$\frac{3}{64} \times \frac{5}{8}$	$\frac{1}{16} \times \frac{3}{4}$	$\frac{1}{16} \times \frac{3}{4}$	$\frac{3}{32} \times 1$	$\frac{3}{32} \times 1\frac{1}{8}$	$\frac{1}{8} \times 1\frac{1}{4}$	$\frac{1}{8} \times 1\frac{3}{8}$

BRITISH ENGINEERING STANDARDS ASSOCIATION

British Standard Fine (B.S.F.) Bright Hexagon Bolts, Nuts, Set Screws, Split Pins, Washers and Studs

Sizes $\frac{7}{32}$- to 2-inch diameter
(All dimensions are in inches)

Nominal size Minus tolerance in decimals Number of threads per inch	A	$\frac{7}{32}$ (−0.0035) 28	$\frac{1}{4}$ (−0.0035) 26	$\frac{5}{16}$ (−0.0035) 22	$\frac{3}{8}$ (−0.0035) 20	$\frac{7}{16}$ (−0.0040) 18	$\frac{1}{2}$ (−0.0040) 16	$\frac{9}{16}$ (−0.0040) 16	$\frac{5}{8}$ (−0.0060) 14
B.S.F. WASHERS									
Diameter of hole:									
Minimum	V	0.233	0.265	0.328	0.390	0.453	0.515	0.588	0.651
Maximum		0.238	0.270	0.333	0.395	0.458	0.520	0.593	0.656
Outside diameter:									
Minimum	W	0.495	0.560	0.620	0.745	0.870	0.995	0.120	1.240
Maximum		0.500	0.565	0.625	0.750	0.875	1.000	1.125	1.250
Thickness:									
Minimum	X	0.054	0.054	0.070	0.070	0.090	0.090	0.100	0.112
Maximum		0.056	0.056	0.072	0.072	0.092	0.092	0.104	0.116
B.S.F. STUDS									
Overall length of stud	Z	Measured from first thread of long end to flat face of short end.							
Long end of stud	AA	Screwed for a length equal to overall length less twice the diameter. Measured from the first to the last full thread.							
Plain part of stud	BB	Equal to the diameter of stud.							
Short end of stud	CC	Screwed for a length equal to the diameter of stud. Measured from the flat end of the stud to the end of the lead of the thread, *i.e.*, to the point where the thread disappears.							
B.S.F. SET SCREWS									
Length of set screw	Y	The form and dimensions of the heads and the rounding at the ends of B.S.F. set screws shall be the same as for B.S.F. bolts.							

BRITISH ENGINEERING STANDARDS ASSOCIATION

British Standard Fine (B.S.F.) Bright Hexagon Bolts, Nuts, Set Screws, Split Pins, Washers and Studs

Sizes $\frac{7}{32}$-to 2-inch diameter
(All Dimensions in Inches)

Nominal size	A	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2
Minus tolerance in decimals		(−0.0060)	(−0.0080)	(−0.0080)	(−0.0080)	(−0.0080)	(−0.0100)	(−0.0100)	(−0.0100
Number of threads per inch		12	11	10	9	9	8	7	7
Width across flats:									
Minimum	B	1.192	1.292	1.468	1.658	1.845	2.200	2.555	2.735
Maximum		1.200	1.300	1.480	1.670	1.860	2.220	2.580	2.760
Approximate width across corners	C	1.39	1.50	1.71	1.93	2.15	2.56	2.98	3.19
B.S.F. BOLTS									
Thickness of bolt head:									
Minimum	D	0.59	0.65	0.76	0.87	0.96	1.18	1.40	1.51
Maximum		0.60	0.66	0.77	0.88	0.98	1.20	1.42	1.53
Minimum length of thread	E	1.500	1.750	2.000	2.250	2.500	3.000	3.500	4.000
When using slotted nut	F	0.57	0.64	0.74	0.86	0.96	1.21	1.44	1.52
When using castle nut	G	0.80	0.87	1.02	1.14	1.29	1.54	1.81	1.98
Drill for split pin hole	L	0.166	0.166	0.199	0.199	0.228	0.228	0.261	0.323
B.S.F. NUTS									
Thickness of nut:									
Minimum	M	0.677	0.740	0.865	0.990	1.105	1.355	1.605	1.730
Maximum		0.687	0.750	0.875	1.000	1.125	1.375	1.625	1.750

B.S.F. LOCK NUTS									
Thickness of lock nut:									
Minimum	**N**	0.448	0.490	0.573	0.656	0.730	0.896	0.063	1.146
Maximum	**N**	0.458	0.500	0.583	0.666	0.750	0.916	1.083	1.166
B.S.F. SLOTTED NUTS									
Thickness of slotted nut:									
Minimum	**M**	0.677	0.740	0.865	0.990	1.105	1.355	1.605	1.730
Maximum	**M**	0.687	0.750	0.875	1.000	1.125	1.375	1.625	1.750
Face of nut to bottom of slot:									
Minimum	**O**	0.443	0.506	0.585	0.710	0.777	0.027	1.230	1.262
Maximum	**O**	0.453	0.516	0.595	0.720	0.797	1.047	1.250	1.282
Approximate width of slot	**S**	0.208	0.208	0.250	0.250	0.290	0.290	0.333	0.416
Approximate depth of slot	**T**	0.234	0.234	0.280	0.280	0.328	0.328	0.375	0.468
B.S.F. CASTLE NUTS									
Thickness of hexagon and from face of nut to bottom of slot:									
Minimum	**M**	0.677	0.740	0.865	0.990	1.105	1.355	1.605	1.730
Maximum	**M**	0.687	0.750	0.875	1.000	1.125	1.375	1.625	1.750
Thickness of castle nut:									
Minimum	**P**	0.911	0.974	1.145	1.270	1.433	1.683	1.980	2.198
Maximum	**P**	0.921	0.984	1.155	1.280	1.453	1.703	2.000	2.218
Diameter of castellated portion:									
Minimum	**Q**	1.165	1.265	1.445	1.635	1.825	2.180	2.535	2.715
Maximum	**Q**	1.185	1.285	1.465	1.655	1.845	2.200	2.555	2.735
Approximate width of slot	**S**	0.208	0.208	0.250	0.250	0.290	0.290	0.333	0.416
Approximate depth of slot	**T**	0.234	0.234	0.280	0.280	0.328	0.328	0.375	0.468
Radius on castellated portion	**R**	0.08	0.08	0.09	0.09	0.10	0.12	0.14	0.14
B.S.F. SPLIT PINS									
Diameter and overall length of split pin	**U**	$\frac{5}{32}$ × 1½	$\frac{5}{32}$ × 1⅝	$\frac{3}{16}$ × 2	$\frac{3}{16}$ × 2¼	$\frac{7}{32}$ × 2¼	$\frac{7}{32}$ × 2½	¼ × 3	$\frac{5}{16}$ × 3¼

BRITISH ENGINEERING STANDARDS ASSOCIATION

BRITISH STANDARD FINE (B.S.F.) BRIGHT HEXAGON BOLTS, NUTS, SET SCREWS SPLIT PINS, WASHERS AND STUDS

Sizes $\frac{7}{32}$- to 2-inch Diameter
(All dimensions are in inches)

Nominal size	A	¾	⅞	1	1⅛	1¼	1½	1¾	2
Minus tolerance in decimals		(—0.0060)	(—0 0080)	(—0.0080)	(—0 0080)	(—0 0080)	(—0.0100)	(—0.0100)	(—0.0100)
Number of threads per inch		12	11	10	9	9	8	7	7
B.S.F. WASHERS									
Diameter of hole:									
Minimum	V	0.776	0.901	1.026	1.151	1.276	1.526	1.776	2.026
Maximum		0.781	0.906	1.031	1.156	1.281	1.531	1.781	2.031
Outside diameter:									
Minimum	W	1.490	1.615	1.865	2.115	2.360	2.860	3.343	3.593
Maximum		1.500	1.625	1.875	2.125	2.375	2.875	3.375	3 625
Thickness:									
Minimum	X	0.140	0.140	0.156	0.172	0.172	0.188	0.208	0.208
Maximum		0.144	0.144	0.160	0.176	0.176	0.192	0.212	0.212

B.S.F. STUDS

Overall length of stud	Z	Measured from first thread of long end to flat face of short end.
Long end of stud	AA	Screwed for a length equal to overall length less twice the diameter. Measured from the first to the last full thread.
Plain part of stud	BB	Equal to the diameter of stud.
Short end of stud	CC	Screwed for a length equal to the diameter of stud. Measured from the flat end of the stud to the end of the lead of the thread, *i.e.*, to the point where the thread disappears.

B.S.F. SET SCREWS

Length of set screw	Y	The form and dimensions of the heads and the rounding at the ends of B.S.F. set screws shall be the same as for B.S.F. bolts.

SECTION XVI

MEASURING AND FITTING

THE VERNIER AND HOW TO READ IT

This method of measuring or of dividing known distances into very small parts is credited to the invention of Pierre Vernier in 1631. The principle is shown in Figs. 1 to 3 and its application in Figs. 4 and 5. In Figs. 1 and 2 both distances 0–1 are the same, but they are divided into different divisions. Calling 0 to 1 = 1 inch, then in Fig. 1 it is clear that moving the lower scale one division will divide the upper one in half. In Fig. 2 the upper scale is divided in half and the lower one in thirds. If the lower scale is moved either way until $\frac{1}{3}$ or $\frac{2}{3}$ comes under the end line, it has moved $\frac{1}{3}$ inch, but if either of these is moved to the center line, then it has only moved $\frac{1}{2}$ of this amount or $\frac{1}{6}$.

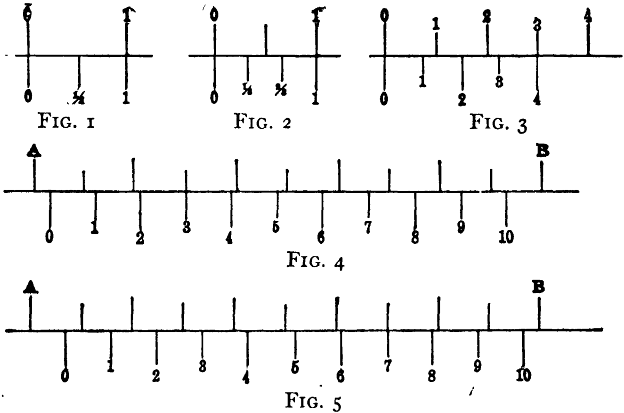


FIG. 1 FIG. 2 FIG. 3

FIG. 4

FIG. 5

FIGS. 1 to 5.—The Vernier and Its Use

Figure 3 shows the usual application of the principle except that it is divided in four parts instead of ten. Here both the scales have four parts, but on the lower scale the four parts just equal three parts of the upper scale. It is evident that if we move the lower scale so that 0 goes to 1 and 4 goes to 4, it will be moved $\frac{1}{4}$ the length of the distance 0–4 on the upper scale. If this distance is 1 inch, each division on the upper scale equals $\frac{1}{4}$ inch, and moving the lower scale so that the line 1 just matches the line next to 0 on the upper scale gives one-fourth of one of these divisions or $\frac{1}{16}$ inch.

Figures 4 and 5 show the usual application in which the lower or vernier scale is divided into 10 parts which equal 9 parts of the upper scale. The same division holds good, however, and when the lower scale is moved so that the first division of the vernier just matches the first line of the scale, it has been moved just one-tenth of a division. In Fig. 4, the third lines match so that it has moved three-tenths and in Fig. 5, seven-tenths of a division. So if *AB* is 1 inch, then each division is $\frac{1}{10}$ inch, and each line of the vernier is one-tenth of that or $\frac{1}{100}$ inch.

To find the reading of any vernier, divide one division of the upper or large scale by the number of divisions in the small scale. So if we had a vernier with 16 divisions in each, the large scale being 1 inch long, then the movement of one division is $\frac{1}{16}$ of $\frac{1}{16}$ or $\frac{1}{256}$ inch.

READING THE MICROMETER

The commercial micrometer consists of a frame, the anvil or fixed measuring point, the spindle, which has a thread cut 40 to the inch on the portion inside the sleeve or barrel, and the thimble which goes outside the sleeve and turns the spindle. One turn of the screw moves the spindle $\frac{1}{40}$ or 0.025 inch, and the marks on the sleeve show the number of turns the screw is moved. Every fourth graduation is marked 1, 2, 3, etc., representing tenths of an inch, or as each mark is 0.025, the first four mean 0.025 × 4 = 0.100, the third means 0.025 × 4 × 3 = 0.300.

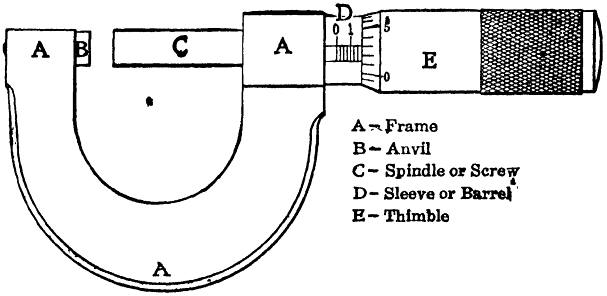


FIG. 6.—Micrometer

The thimble has a beveled edge divided into 25 parts and numbered 0, 5, 10, 15, 20, and to 0 again. Each of these means $\frac{1}{25}$ of a turn or $\frac{1}{25}$ of $\frac{1}{40}$ = 1/1,000 inch. To read, multiply the marks on the barrel by 25, and add the graduations on the edge of the thimble. In Fig. 6, there are seven marks on the sleeve and three on the thimble, so we say 7 × 25 = 175, plus 3 = 178 or 0.178.

In shop practice, it is common to read them by using mental addition and not multiplying. Beginning at the largest number shown on the sleeve and calling it hundreds and adding 25 for each mark, we say, in the case shown, 100 and 25, 50, 75 and then add the numbers shown on the thimble 3, making 0.178 in all. If it showed 4 and one mark, with the thimble showing eight marks, the reading would be 400 + 25 + 8 = 433 thousandths or 0.433.

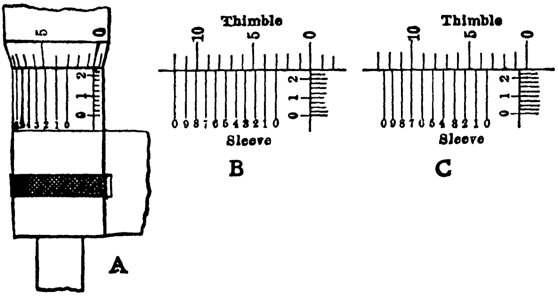


Fig. 7.—Micrometer Graduations

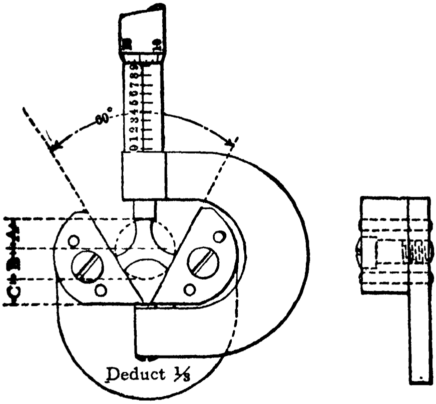


Fig. 8.—Measuring Three-Fluted Tools

The Ten-Thousandth Micrometer

This adds a vernier to the micrometer sleeve or barrel, as shown in Fig. 7, which is read the same as any vernier as has been explained. First note the thousandths, as in the ordinary micrometer, and then look at the line on the sleeve which just matches a line on the thimble. If the zero lines match on both thimble, and sleeve, the measurement is in even thousandths as at *B* which reads 0.250.

At C the seventh line matches a line on the thimble so the reading is 0.2507 inch.

Measuring Three-Fluted Tools with the Micrometer

In Fig. 8 is shown a V block or gage for measuring three-fluted drills, counterbores, etc.

The angle being 60 degrees, the distances A, B, and C are equal. Consequently, to determine the correct diameter of the piece to be measured, apply the gage as indicated in the sketch and deduct one-third of the total measurement.

The use of this gage has a decided advantage over the old way of soldering on a piece of metal opposite a tooth or boring out a ring to fit to.

Using a standard 60-degree triangle for setting and a few different sizes of standard cylindrical plug gages for testing, the V block may be easily and very accurately made.

USE OF CALIPERS

Side Play of Calipers in Boring Holes Larger than a Piece of Known Diameter

The following is an approximate rule for obtaining the variation in the size of a hole corresponding to a given amount of side play in the calipers. The rule has the merit of extreme simplicity and can be applied equally well to all diameters, except the very smallest. In most cases, the calculation is so simple that it can be done mentally without having recourse to pencil or paper.

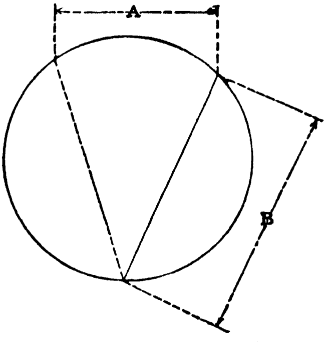


Fig. 9.—Caliper Side Play

The Calculation

Let A in Fig. 9 = side play of calipers or end measuring rod, *in sixteenths of an inch.*

B = dimensions to which calipers are set, or length of measuring rod, *in inches.*

C = difference between diameter of hole and length of B *in thousandths of an inch.*

Then $C = \frac{A^2}{2B}$, within a very small limit.

Example.—A standard-end measuring rod, 5½ inches long, has ⅜ inch of side play in a hole. What is the size of the hole? In this case $A = 6$, and $B = 5\frac{1}{2}$. Apply the above formula:

$$C = \frac{6 \times 6}{11} = \frac{36}{11} = 3.27 \text{ thousandths of an inch, or } 0.00327 \text{ inch.}$$

The diameter of the hole, therefore, is 5½ + 0.00327 or 5.50327.

The method will be found to be correct within a limit of about 0.0002 inch if the amount of side play is not more than one-eighth of the diameter of the hole for holes up to 6 inches diameter; within 0.0005 inch for holes from 6 inches up to 12 inches; and within 0.001 for holes from 12 inches up to 24 inches.

BORE GAGING BY ROCK OF THE PIN GAGE[1]

In order to determine the bore of a bearing which is oversize so as to permit a running clearance, the length of the pin gage is made the same as the shaft diameter. After measuring the rock of the pin gage, the clearance may be found in Table 1 (expressed in thousandths of an inch).

EXAMPLE.—The measurement of a nominal 6-inch bearing bore shows 0.410 inch rock. The table specifies 0.003 inch clearance for 0.379 inch rock and 0.004 inch clearance for 0.438 inch rock. By interpolation 0.410 inch rock results in a clearance of 0.0035 inch.

Table 2 is used where the bore is undersize, such as may be the case when a press fit is required. The pin gage for such bores is made 0.01 inch less than the shaft.

EXAMPLE.—For a 5-inch diameter shaft the pin is made 4.99 inches long. Assuming a rock of 0.44 inch, Table 2 shows 0.42 inch rock as indicating 0.0055 inch press fit, 0.45 inch rock as 0.005 inch press fit. Therefore, 0.44 inch rock would by interpolation be equivalent to a 0.0052 inch press fit.

INTERCHANGEABLE MANUFACTURE

Standard or Basic Hole Practice

Strict interchangeability consists in making the different parts of a mechanism so uniform in size and contour that each part will fit and properly function in any one of the whole number of mechanisms, no matter when or where it is made. If the quantities being manufactured are large, interchangeable manufacture is economical because it entails a correct system of gaging as well as manufacture. This system does not produce any more scrap or spoiled work than any other—it only indicates by inspection methods which pieces are definitely within or without the prescribed dimensions as represented by the gages.

It is a generally accepted practice in the best shops to have the minimum dimension of the hole or receiving member standard. This is because the means of measuring are better adapted to such standards as plugs, blocks, and end measuring rods. Correct standards of this type are easier to produce and as they form a ready means of directly checking the external member of a pair of mating parts, they at once establish the minimum dimension at the logical place. Any external member which will not receive the gage is too small, that is, it is below the standard size.

The mating gage to a plug, block, or rod gage (or the other member of a pair of gages) thus directly checks the internal member against being too large or over the standard size. Therefore,

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[1] J. I. Hommel, Standards Engineer, Westinghouse Electric & Manufacturing Company.

TABLE 1.—BEARING CLEARANCE BY THE ROCK OF THE PIN GAGE

Shaft Diameter or Length of Pin Gage, in Inches	Allowances, in Inches																			
	0.0005	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009	0.010	0.011	0.012	0.013	0.014	0.015	0.016	0.017	0.018	0.019	0.020
	Rock of Pin Gage in Bore																			
3	0.110	0.155	0.219	0.268	0.309	0.346	0.379													
4	0.126	0.179	0.253	0.310	0.357	0.399	0.437	0.472												
5	0.141	0.200	0.283	0.346	0.400	0.447	0.489	0.528												
6	0.155	0.219	0.310	0.379	0.438	0.489	0.536	0.579	0.610											
7	0.167	0.237	0.334	0.410	0.473	0.529	0.579	0.625	0.668	0.709										
8	0.179	0.253	0.358	0.438	0.506	0.505	0.619	0.669	0.715	0.758	0.799									
9	0.190	0.268	0.379	0.465	0.536	0.600	0.657	0.709	0.758	0.804	0.847									
10	0.200	0.283	0.400	0.490	0.565	0.632	0.692	0.748	0.799	0.848	0.893	0.937								
11	0.210	0.297	0.419	0.514	0.593	0.663	0.726	0.784	0.838	0.889	0.937	0.983	1.026							
12	0.220	0.310	0.438	0.536	0.619	0.693	0.759	0.819	0.876	0.929	0.979	1.028	1.072	1.116						
13	0.229	0.322	0.456	0.558	0.645	0.721	0.789	0.853	0.911	0.967	1.019	1.069	1.116	1.161	1.205					
14	0.236	0.335	0.473	0.579	0.669	0.748	0.819	0.885	0.946	1.003	1.057	1.109	1.158	1.205	1.251	1.294				
15	0.245	0.347	0.490	0.600	0.693	0.774	0.848	0.916	0.979	1.039	1.095	1.148	1.199	1.248	1.295	1.340				
16	0.253	0.358	0.506	0.620	0.715	0.800	0.876	0.946	1.011	1.073	1.131	1.186	1.238	1.289	1.337	1.384	1.429			
17	0.261	0.368	0.522	0.639	0.737	0.824	0.903	0.975	1.042	1.106	1.105	1.222	1.276	1.328	1.379	1.427	1.473	1.519		
18	0.269	0.379	0.536	0.657	0.758	0.848	0.929	1.008	1.073	1.138	1.199	1.258	1.313	1.367	1.418	1.468	1.516	1.563	1.608	
19	0.276	0.390	0.551	0.675	0.779	0.871	0.955	1.031	1.102	1.169	1.232	1.292	1.350	1.404	1.457	1.509	1.558	1.606	1.652	1.697	
20	0.283	0.400	0.565	0.692	0.800	0.894	0.979	1.057	1.131	1.199	1.264	1.326	1.385	1.441	1.495	1.548	1.598	1.648	1.695	1.742	1.787

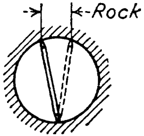

Table 2.—Press Fit by the Rock of the Pin Gage

Diameter of Shaft, in Inches	Length of Pin Gage, in Inches	Press-Fit Allowances, in Thousandths of an Inch															
		Less 9	Less 8	Less 7	Less 6½	Less 6	Less 5½	Less 5	Less 4½	Less 4	Less 3½	Less 3	Less 2½	Less 2	Less 1½	Less 1	Less ½
3	2.99	0.16	0.22	0.27	0.29	0.31	0.33	0.35	0.36	0.38	0.39	0.41	0.42	0.44	0.45	0.46	0.48
3½	3.49	0.17	0.24	0.29	0.31	0.33	0.35	0.37	0.39	0.41	0.42	0.44	0.46	0.47	0.49	0.50	0.51
4	3.99	0.18	0.25	0.31	0.33	0.36	0.38	0.40	0.42	0.44	0.46	0.47	0.49	0.51	0.52	0.54	0.55
4½	4.49	0.19	0.27	0.33	0.35	0.38	0.40	0.42	0.44	0.46	0.48	0.50	0.52	0.53	0.55	0.57	0.58
5	4.99	0.20	0.28	0.35	0.37	0.40	0.42	0.45	0.47	0.49	0.51	0.53	0.55	0.56	0.58	0.60	0.62
5½	5.49	0.21	0.30	0.36	0.39	0.42	0.44	0.47	0.49	0.51	0.53	0.55	0.57	0.59	0.61	0.63	0.64
6	5.99	0.22	0.31	0.38	0.41	0.44	0.46	0.49	0.51	0.54	0.56	0.58	0.60	0.62	0.64	0.66	0.67
6½	6.49	0.23	0.32	0.39	0.43	0.46	0.48	0.51	0.53	0.56	0.58	0.60	0.62	0.64	0.66	0.68	0.70
7	6.99	0.24	0.33	0.41	0.44	0.47	0.50	0.53	0.55	0.58	0.60	0.63	0.65	0.67	0.69	0.71	0.73
7½	7.49	0.24	0.35	0.42	0.46	0.49	0.52	0.55	0.57	0.60	0.62	0.65	0.67	0.69	0.71	0.73	0.75
8	7.99	0.25	0.36	0.44	0.47	0.51	0.54	0.57	0.59	0.62	0.65	0.67	0.69	0.72	0.74	0.76	0.78
8½	8.49	0.26	0.37	0.45	0.49	0.52	0 55	0.58	0.61	0.64	0.66	0.69	0.71	0.74	0.76	0.78	0.80
9	8.99	0.27	0.38	0.47	0.50	0.54	0.57	0.60	0.63	0.66	0.68	0.71	0.73	0.76	0.78	0.80	0.83
9½	9.49	0.28	0.39	0.48	0.52	0.55	0.58	0.62	0.65	0.67	0.70	0.73	0.75	0.78	0.80	0.83	0.85
10	9.99	0.28	0.40	0.49	0.53	0.57	0.60	0.63	0.66	0.69	0.72	0.75	0.77	0.80	0.82	0.85	0.87
10½	10.49	0.29	0.41	0.50	0.54	0.58	0.61	0.65	0.68	0.71	0.74	0.77	0.79	0.82	0.84	0.87	0.89
11	10.99	0.30	0.42	0.51	0.55	0.59	0.63	0.66	0.70	0.73	0.76	0.78	0.81	0.84	0.86	0.89	0.91
11½	11.49	0.30	0.43	0.52	0.57	0.60	0.64	0.68	0.71	0.74	0.77	0.80	0.83	0.86	0.88	0.91	0.93
12	11.99	0.31	0.44	0.54	0.58	0.62	0.66	0.69	0.73	0.76	0.79	0.82	0.85	0.88	0.90	0.93	0.95
12½	12.49	0.32	0.45	0.55	0.59	0.63	0.67	0.71	0.74	0.77	0.81	0.84	0.87	0.89	0.92	0.95	0.97
13	12 99	0.32	0.46	0.56	0.60	0.65	0.68	0.72	0.76	0.79	0.82	0.85	0.88	0.91	0.94	0.97	0.99
13½	13 49	0.33	0.46	0.57	0.61	0.66	0.70	0.73	0.77	0.80	0.84	0.87	0.90	0.93	0.96	0.99	1.01
14	13.99	0.34	0.47	0.58	0.63	0.67	0.71	0.75	0.78	0.82	0.85	0.89	0.92	0.95	0.98	1.00	1.03
14½	14.49	0.34	0.48	0.59	0.64	0.68	0.72	0.76	0.80	0.83	0.87	0.90	0.93	0.96	0.99	1.02	1.05
15	14.99	0.35	0.49	0.60	0.65	0.69	0.74	0.77	0.81	0.85	0.88	0.92	0.95	0.98	1.01	1.04	1.07
15½	15.49	0.35	0.50	0.61	0.66	0.70	0.75	0.79	0.83	0.86	0.90	0.93	0.96	1.00	1.03	1.06	1.08
16	15.99	0.36	0.51	0.62	0.67	0.72	0.76	0.80	0.84	0.88	0.91	0.95	0.98	1.01	1.04	1.07	1.10
16½	16.49	0.36	0.51	0.63	0.68	0.73	0.77	0.81	0.85	0.89	0.93	0.96	0.99	1.03	1.06	1.09	1.12
17	16.99	0.37	0.52	0.64	0.69	0.74	0.78	0.82	0.86	0.90	0.94	0.98	1.01	1.04	1.07	1.11	1.14
17½	17.49	0.37	0.53	0.65	0.70	0.75	0.79	0.84	0.88	0.92	0.95	0.99	1.02	1.06	1.09	1.12	1.15
18	17.99	0.38	0.54	0.66	0.71	0.76	0.80	0.85	0.89	0.93	0.97	1.00	1.04	1.07	1.11	1.14	1.17
18½	18.49	0.38	0.54	0.67	0.72	0.77	0.82	0.86	0.90	0.94	0.98	1.02	1.05	1.09	1.12	1.15	1.19
19	18.99	0.39	0.55	0.68	9.73	0.78	0.83	0.87	0 91	0.96	0.99	1.03	1.07	1.10	1.14	1.17	1.20
19½	19.49	0.39	0.56	0.68	0.74	0.79	0.84	0.88	0.93	0.97	1.01	1.04	1.08	1.12	1.16	1.18	1.22
20	19.99	0.40	0.57	0.69	0.75	0.80	0.85	0 89	0.94	0 98	1.02	1.06	1.10	1.13	1.17	1.20	1.23

standard gages should fix this point of the dimensions of the most difficult fit required in interchangeable manufacture.

In a pair of mating parts that fit and move freely, there is a space or clearance between the mating surfaces. If this space is reduced gradually, a condition will ultimately be reached in which there is no space or clearance between the parts, that is, the mating parts are together, metal to metal, without shake. Then any movement of the parts one within the other will require some force. If this condition of tightness is represented by a horizontal line, which we might call "zero," then this zero line marks the low limit in the dimension of the external member and the high limit of the dimension of the internal member.

Any overlapping of this line by the dimensions of either member of a mating pair tends to produce tightness, and any deviation away from this line without crossing it will tend to produce looseness. This zero line, then, is the logical place to coincide with the standard. The best experience in interchangeable manufacture has verified this, and the best shops use it.

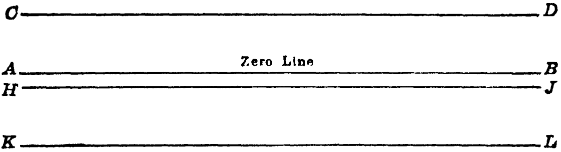

FIG. 10.—Diagram of Tolerances and Allowance

In Fig. 10, the zero line *AB* corresponds to the exact standard size and the line *CD* represents the largest allowable dimension on the tools for external members. The space between the lines *AB* and *CD* is the manufacturing tolerance and also the wear limit on these tools. As soon as the tools have worn so that the standard gage will not go in the hole, their use is stopped. It might be asked, Why not continue their use to, say, 0.001 inch undersize before stopping and so get more wear out of the tool? The obvious answer is that the standard gage will not check it, and hence the gage is of no use. This is called "unilateral" tolerance.

The tolerance on the tool above the minimum size determines the amount of wear on the tool and not the relation of the minimum size to the standard. If 0.002-inch wear is desired on a tool, then there must be 0.002-inch more looseness when the tool begins to work and this should be above standard, as nothing is gained by starting it at 0.001 inch above standard and stopping at 0.001 inch under standard. This would be "bilateral" tolerance.

The line *HJ* represents the largest allowable dimension on the shaft or internal member, and the space between this line and the zero line is the minimum allowance, which must never be intentionally encroached upon. It is intended for a predetermined looseness for oil and freedom of fits to prevent seizing.

This space between the zero line and line *HJ* is the difference allowed between the dimensions of the smallest external member and the largest internal member by the designer for the express purpose of establishing the tightest permissible fit.

It is necessary to have a manufacturing tolerance when a large number of these are made. The line *KL* represents the smallest allowable dimension on the shaft or internal member, and the space between the lines *HJ* and *KL* is the tolerance allowed for manufacturing the internal members.

The maximum looseness is represented by the distance between the lines *CD* and *KL*. The greatest tightness is represented by the distance between the zero line *AB* and *HJ*. In this case, the limits for the external member are from standard to *CD* oversize, and the limits for internal member are from *HJ* to *KL*, both undersize.

The space between the lines *AB* and *HJ* is commonly called neutral space, indicating that it is not to be encroached upon by the intrusion of the dimensions of either member of a pair of mating parts. In force or shrink fits, there is no neutral space, but the allowance provides for less than a space or an imaginary neutral space occupied by part of each member. Figures 11 and 12 show four common fits. For any class of fit—tight, loose or medium—the standard gage fixes the low limit for the size of the hole or external part. If these parts are made with precision tools, such as reamers or broaches, all these holes can be made with the same tools and carried in stock for all fits. The methods of finishing the shaft or internal members vary so widely that standard tools for this purpose are not commonly carried in stock. The desired kind of fit is secured by making the internal member the required amount undersize. It has been common practice for years to make shafting and cold drawn steel which is used for this purpose about 0.001 inch or more under the standard size to ensure interchangeability in standard holes.

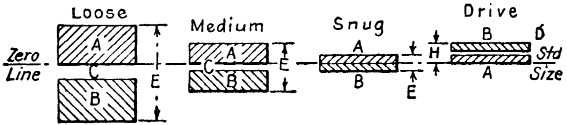

FIG. 11. FIG. 12.

FIGS. 11 and 12.—Four Common Fits

It will be noted that the same minimum plug or "go" gage is used for all holes regardless of fit. This "go" gage is exactly the same as the calibrated standard and is, therefore, checked by it.

Should it be required either to increase or to decrease tolerances, this gage remains unchanged, and the interchangeability is not affected. Increasing the tolerance on the external member increases the size of the "not go" gage, resulting only in more freedom of fit.

The Newall System of gaging, in great favor in England before the standards of the British Engineers Association were adapted, has as its basis a "uniform standard hole," as being the only practicable workable basis for true interchangeability. This should also be extended to screw-thread products. Taps are not adjustable—the dies are. The standard threaded plug is easier to produce and calibrate or verify. The threaded ring gages are adjustable, and everything points to the logic of extending standard hole practice to screw-thread products.

Interchangeability in screw-thread fits has also been determined by the National Screw Thread Commission, interchangeability being secured through standardizing the tapped hole. This is done by making the minimum size of all tapped holes basic, regardless of the kind of fit desired. The four classes of thread fits are loose, free, medium, and close.

Complete data concerning screw-thread fits will be found in Secs. I and II. These include straight threads and pipe threads of both American and British standards, as well as oil-well casings, and hose couplings. Methods of measurement and standards for machine fits in general are given on the pages that follow.

Users of the metric system advocate 1 micron = 0.00004 inch as a unit for the highest grade of fit.

The Standard Inch

Standard measurements in the past have been taken from metal bars graduated as exactly as could be done at the time and at standard temperature. The newer method is to measure by light waves instead of standard bars, the standard inch now being taken as 39,450.3 wave lengths of cadmium light.

The accepted relation between the inch and the millimeter is that 25.4 millimeters equal one inch.

Micro-Inch and Micron

A new term has been coined in the United States to designate one-millionth inch—"micro-inch." Care should be taken not to confuse this with the French term "micron," which is one-millionth of a meter, or 0.00003937 inch.

MEASURING WITH LIGHT WAVES*

Light waves have made possible extremely accurate inspection and production in many industries. The manufacture of precision gage blocks was developed in this country with the aid of light waves. The electrical-refrigerator industry has perfected gastight pump seals by having this easy and accurate method of inspecting flat-lapped surfaces. Likewise, diesel engine, aircraft, and other precision parts are known by light waves to be perfect.

The optical flat is now a common shop tool. It is essential in the maintenance of amplifying gages, micrometers, snap gages, and measuring machines. It greatly aids in realizing "quarter-tenths" and "the last hundred-thousandth," as it instantly shows worn spots in anvils, measuring contacts, and gage-block standards. The optical flat shows errors in units of hundred-thousandths and millionths of an inch, yet its use is extremely simple and direct.

Equipment Required

In general a light-wave measuring equipment includes the following:

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* By H. L. Van Keuren.

Two or more optical flats.
One monochromatic light.
One set of precision gage-block standards.

An optical flat is simply a piece of clear, hard glass which is carefully ground and polished until one surface is perfectly flat. It has no magnifying power but depends for its usefulness upon the degree of accuracy of the one flat surface. A good working flat should be a true plane within 0.000005 inch (5 millionths), and a master or reference flat should be accurate within 0.0000025 inch (2½ millionths). An accurate steel flat may be used for a bottom flat with the advantage of lower cost and long life.

The monochromatic light is a light of one color or wave length. Daylight or white light contains all the colors and wave lengths from about 16 to 26 millionths inch. A convenient form of monochromatic light is shown in Fig. 13.

The monochromatic light is provided with a special gas-filled tube similar to those used in neon signs and operated by a 5,000-volt transformer connected to a 110-volt 60-cycle supply. The light emitted has a value of 11.6 millionths inch per dark band and is so strongly monochromatic or of one predominating wave length that bands are clearly visible when the separation of surfaces is as much as 0.005 inch. Thus. for testing flatness the optical flat need not touch the surface being tested. Interference bands seen with daylight are a series of colors similar to the colors of a rainbow, and an approximation of 10 millionths inch per band may be used for the measuring unit.

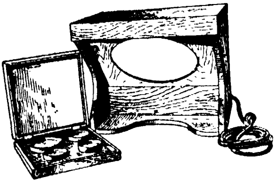

FIG. 13.—Light-Wave Measuring Equipment

Testing Flatness

When an optical flat is placed on a nearly flat lapped or polished reflecting surface, interference bands or alternate light and dark spaces will be immediately seen if a monochromatic light is available. With daylight, it is necessary to exclude all dust particles, moisture, or oil and to bring the surfaces into very close contact.

A visual examination of the bands will then indicate the flatness as follows:

1. Straight bands show a perfectly flat surface.
2. Curved bands show the surface is not flat.

AMOUNT OF FLATNESS ERROR

If the bands curve the distance between successive bands, the surface tested is out of flat 11.6 millionths inch. This condition is shown in *b*, Fig. 14. Here the dotted line connecting the ends of a band just intersects the previous band. In practice, a shadow from a straight edge may be used for the dotted line, but in general, the flatness error may be estimated to sufficient accuracy. Other conditions of surface error are shown in Fig. 14.

The Principle of the Wedge of Air

The conditions which exist when an optical flat is placed on a gage block and interference bands made visible may best be explained by referring to the diagrammatic sketch of Fig. 15, which shows the wedge or angular contact greatly exaggerated and the surface of the gage block perfectly flat.

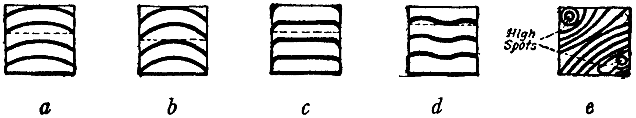

FIG. 14.—Different Conditions and Degrees of Surface Error. Heavy Lines Indicate Edge in Contact with Flat

a, Convex surface—side edges low 6 millionths. *b*, Convex surface—side edges low 12 millionths. *c*, Nearly flat—side edges low or rounded 6 millionths. *d*, Surface both convex and concave—hollow in center, higher each side of center and lower at side edges. Error 3 millionths. *e*, Note 2 high spots with 12 bands between, indicating a valley 6 bands or 75 millionths deep.

The interference bands are caused by the fact that the light reflected from the surface of the gage interferes with the light reflected from the undersurface of the flat. The dark interference bands indicate vertical distances of one-half wave lengths of light. This is strictly true when looking directly down on the surfaces and practically true when viewed at a slight angle.

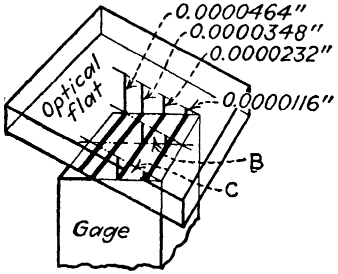

FIG. 15.—The Wedge of Air

The first band nearest the point of contact indicates that the vertical distance between the gage and the flat is 11.6 millionths inch; the second band shows a vertical distance of 22 millionths inch; etc. If the flat is pressed down on the gage, the wedge becomes thin and fewer bands or steps of 11.6 millionths are present.

If the surfaces are accurately flat, they can be brought together so close that the distance at any point is less than 0.000005 inch, and the bands disappear. Thus, when a gage block is wrung on a flat, it is in intimate contact, being held on the flat by a very thin film of moisture or grease within 2 or 3 millionths inch. It is surprising that, although this film is but a few millionths of an inch thick, it is plainly visible through a glass flat.

Referring again to Fig. 15, the following facts should be noted:

1. Straight bands indicate a flat surface.
2. The number of bands shows the steepness of the wedge of air and is the unit of measurement showing differences of thickness or length between the gage-block standard and the piece being measured.
3. The direction of the wedge is at right angles to the direction of the bands.

Checking Gage Blocks

When checking worn gage blocks against a known master block, both gages are wrung on an optical flat, as shown in Fig. 16. An examination of the bands reveals the following facts:

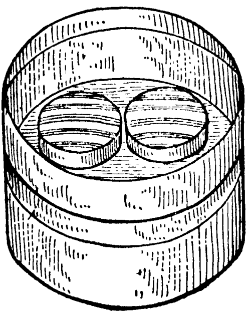

FIG. 16.—Interference Bands on Two Gage Blocks Being Compared for Flatness, Length, and Parallelism

1. The bands are slightly curved. This indicates that the surfaces of the gage blocks are not perfectly flat. Straight bands indicate a flat surface, curved bands, a curved surface. If the bands curve around the "point of contact" or the point where the glass touches the surface being examined, the surface is *convex*. If the curvature of the bands is just the reverse, the surface is *concave*.
2. The pronounced light spot and the more clearly defined bands near the observer, Fig. 16, indicate the point of contact. As the bands curve around the point of contact, the surfaces of the gage block are convex.
3. The bands on each gage curve about two-tenths of the distance between successive bands, and the error of flatness is therefore two-tenths of one measuring unit (11.6 millionths) or 2.32 millionths inch.
4. The upper flat is sloping upward toward the rear at the rate of 11.6 millionths per dark band. There is, therefore, a wedge of air between the upper and the gage blocks. At the rear of the right-hand gage, the wedge is five times 11.6, or 58 millionths inch thick. At the rear of the left-hand gage, the wedge is 5½ times 11.6 millionths or 63.8 millionths inch thick. The gage on the left is, therefore, shorter or smaller than the gage on the right by one-half band, or a little under 6 millionths inch.
5. It will be noted also that each band on the left-hand gage occurs about one-half band lower down on the wedge than the bands on the right-hand gage. Thus, the comparison of length may be referred to the first band on each gage, or to the second, or to any successive band.
6. The bands on both gages, although slightly curved, are practically parallel, indicating that the upper surfaces of the two

gages as they are wrung on the lower flat are parallel within 1 or 2 millionths inch.

Thus, with one observation, there are obtained the flatness, parallelism, and length comparison of two gage blocks. Both gages are measured at the same time and at the same temperature. An accuracy of 1 or 2 millionths of an inch is secured, and there are no complicated settings or parts to introduce error. The accuracy of the flat may be known by testing them together or, better, by testing three flats in various combinations.

Applying the Principle of the Wedge

Measurements of diameter or length are made by wringing a gage-block standard on the lower optical flat and then bringing the upper optical flat in contact with both the gage block and the part being measured. The upper flat must be pressed down until contact is secured on some point of the gage block and the part being measured. The location of the point of contact on the gage block will depend on the oversize or undersize condition of the part being measured.

It is essential that the location of the point of contact on the gage block be determined. This is readily apparent in daylight by the absence of color, the grayish surface of the steel gage block being seen.

The gage block, in reality, establishes a parallel reference plane 1 inch—if it is a 1.000-inch gage—above the lower or base surface. The amount that the part is over or under standard is then easily determined by counting the bands starting from the point of contact on the gage block and continuing to the point of contact on the part being measured.

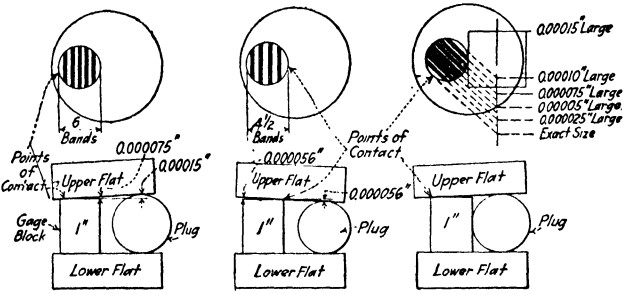

FIG. 17.—Measuring by Light Wave

Figure 17 shows in a diagrammatic way how the amount oversize or undersize is determined for measuring plug gages. The same principles apply for making other measurements, such as the measurement of pitch diameter of thread gages.

Among the uses of light waves should be mentioned the following:

1. Comparing precision gage blocks.
2. Testing flatness of micrometer or measuring-machine contacts, snap gage jaws or other flat gaging surface.

3. Measuring diameters of plug gages, steel balls, rollers, thread gages, thread-measuring wires and accurate cylindrical parts.
4. Measuring thickness of watch hairsprings, thin sheet metal, parchment or like material.
5. Determining coefficient of expansion of metals or other substances.
6. Determining amount of contraction of dental amalgams or cements during the setting process.

The Light-Wave Micrometer

A very convenient measuring instrument which combines the extreme sensitivity of light waves with the utility of the micrometer is shown in Fig. 18. In this instrument the light-wave bands move past a reference line as pressure is applied on the piece being measured. Any measuring pressure, from just contact or zero pressure up to 2 pounds, may be used. Because the exact pressure of measurement can be exactly duplicated, the micrometer reading can be duplicated to 0.00001 inch. The 6-inch diameter head is graduated to 0.0001 inch, permitting readings to 0.00001 inch.

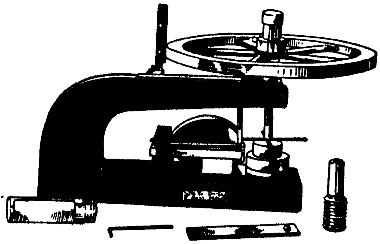

FIG. 18.—Light-Wave Micrometer

The light-wave micrometer measures length, thickness, and diameter of machine parts and gages—out-of-roundness of cylinders, three-wire measurement of screw threads—and is particularly useful in measuring soft materials, such as rubber, paper, leather, textiles, hairsprings, fine wires, dental amalgams, etc., because a very light measuring pressure can be used. The measurements are made between flat parallel surfaces, thus reducing indentation of the measuring contacts in the piece being measured.

TOLERANCES AND ALLOWANCES FOR METAL FITS

Introductory

A committee of the A. S. M. E. on plain limit gages for general engineering work, believing that the terms and definitions used should, as nearly as possible, conform to those in common use, adopted the following fundamentals and definitions.

Fundamentals

Direction of Tolerance on Gages.—The extreme sizes for all plain limit gages shall not exceed the extreme limits of the part to be gaged. All variations in the gages, whatever their cause or purpose, shall bring these gages within these extreme limits. Thus a gage which represents a minimum limit may be larger, but never smaller, than the minimum size specified for the part to be gaged; likewise the gage which represents a maximum limit may be smaller, but never larger, than the maximum size specified for the part to be gaged.

The temperature of 68°F. (20°C.) shall be the standard for plain limit gages.

The final result sought by gaging is interchangeable manufacture in some degree. This means that the parts of a mechanism can be assembled without *fitting* one part to another and that when assembled the parts will function properly.

Applied to manufactured material, the result sought is sufficient uniformity in size and contour to adapt the material without further fitting to the requirements of the industries. The fundamental principle involved in interchangeable manufacture requires that "a system of standardization and classification of fits shall establish a clearly defined line at which interference between mating parts begins." Hence:

1. The standard or basic size, as physically represented by a correct standard master gage, represents the line at which this interference begins between mating parts.

2. It is the minimum size of the external members of all mating parts of standardized practice, regardless of the kind of fit.

3. It is the maximum size of internal members of all mating parts where interference begins or that fit metal to metal.[1]

4. The limits of the component as physically represented by the limit master gages shall not be exceeded as a result of either tolerance or wear of the gages.

5. "Go" gages, or the equivalent verification of all the factors involved in the fit, are necessary to prevent interference of mating parts.

In the case of force fits, "go" gages are necessary to determine the maximum amount of interference between mating parts.

6. "Not go" gages, or the equivalent verification of the determining factor, are necessary to prevent the maximum looseness of mating parts exceeding the limits specified.

In the case of force fits, "not go" gages are necessary to determine the minimum amount of interference between mating parts.

Definitions

Gaging.—A process of measuring manufactured materials to assure the specified uniformity of size and contour required by the industries.

Gage.—A device for determining whether or not one or more of the dimensions of a manufactured part are within specified limits.

1. *Ring Gage.*—One whose inside measuring surfaces are circular in form. The measuring surfaces may be cylindrical or conical.

2. *Plug Gage.*—One whose outside measuring surfaces are arranged to verify the specified uniformity of holes. A plug gage may be straight or tapered and of any cross-sectional shape.

3. *Receiving Gage.*—One whose inside measuring surfaces are arranged to verify the specified uniformity of size and contour of manufactured material.

4. *Indicating Gage.*—One that exhibits visually the variations in the uniformity of dimensions or contour, the amount of the variation being indicated by lever on graduated scale, dial, flush pin, plunger gages, etc.

5. *Snap Gage.*—A fixed gage arranged with inside measuring surfaces for calipering diameters, lengths, thicknesses, etc.

6. *Caliper Gage.*—One which, for internal members, is similar to a snap gage, and for external members, is similar to a plug gage.

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[1] The condition of 2 and 3 is represented by a mating pair of correctly fitting standard gages.

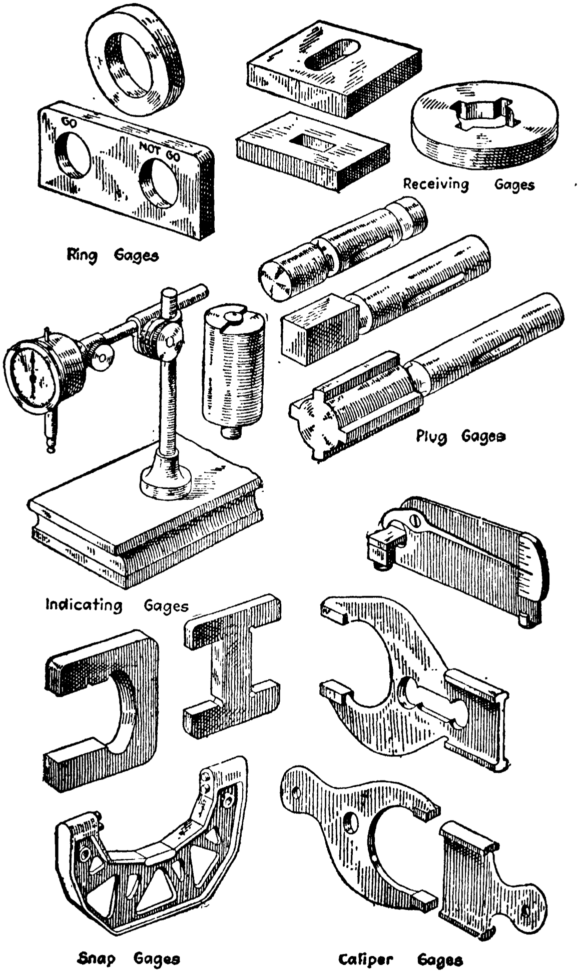

FIG. 19.—Types of Gages

Standard.—A physical representation of a form, dimension or size established by law or by general usage and consent.

Standard Sizes.—A series of recognized or accepted sizes corresponding to various subdivisions of a recognized unit of length, such as the yard or the meter. These are usually expressed in inches or in millimeters, sometimes by arbitrary numbers or letters.

NOTE.—The industries, by common consent, have chosen several different series important for interchangeable manufacture. For instance, the common fractions of an inch are commonly called standard sizes, such as $\frac{1}{8}$, $\frac{3}{16}$, $\frac{1}{4}$, $\frac{5}{16}$ inch, etc.

Nominal Size.—A designation given to the subdivision of the unit of length having no specified limits of accuracy, but indicating a close approximation to a standard size.

Basic Size.—The exact theoretical size from which all limiting variations are made.

Allowance (Neutral Zone)—An intentional difference in the dimensions of mating parts; or the minimum clearance space which is intended between mating parts. It represents the condition of the tightest permissible fit, or the largest internal member mated with the smallest external member. It is to provide for different classes of fit.

EXAMPLE.—A shaft dimensioned 0.874 inch and a hole dimensioned 0.875 inch represent an allowance of 0.001 inch. The same hole with a shaft dimensioned 0.876 inch represents an allowance of 0.001 inch also; but, as the shaft is larger than the hole, this allowance becomes a negative quantity. (See "Explanatory Notes," page 751.)

Tolerance.—The amount of variation permitted in the size of a part.

NOTE.—In the example under Allowance, the ideal condition and the tightest fit permissible have been given; but in manufacturing large numbers of pieces, these sizes could not be produced exactly, so variations must be made that will not prevent their proper functioning but will enable them to be produced. These variations must therefore tend toward greater looseness. Then, if a manufacturing tolerance of 0.001 inch is required on each member, they would be dimensioned as follows:

Shaft	0.874 inch	+ 0.000 inch
		− 0.001 inch
Hole	0.875 inch	+ 0.001 inch
		− 0.000 inch

This defines a condition in which the greatest looseness is 0.003 inch, and the greatest tightness gives a clearance of 0.001 inch.

Neutral Zone.—See Allowance.

Limits.—The extreme permissible dimensions of a part.

Master Gage.—A gage whose gaging dimensions represent as exactly as possible the physical dimensions of the component. It is the gage with which all other gages and all dimensions of manufactured material are finally checked or compared, either by direct check or by comparison.

Inspection Gages.—Gages for the use of the manufacturer or purchaser in accepting the product. These gages must not accept any product which the master gages will reject.

TABLE 3.—STANDARD FITS, SUMMARY OF TIGHTEST, LOOSEST AND SELECTED CONDITION FOR ALL CLASSES OF FIT
(All Dimensions in Inches)

Size			Loose Fit (Class 1)		Free Fit (Class 2)		Medium Fit (Class 3)		Snug Fit (Class 4)		Wringing Fit (Class 5)		Tight Fit (Class 6)	Medium Force Fit (Class 7)	Heavy Force and Shrink Fit (Class 8)
			Tightest Fit	Loosest Fit	Tightest Fit	Loosest Fit	Tightest Fit	Loosest Fit	Tightest Fit	Loosest Fit	Tightest Fit	Loosest Fit	Selected Fit	Selected Fit	Selected Fit
			Allowance	Allowance + Tolerances	Allowance	Allowance + Tolerances	Allowance	Allowance + Tolerances	Allowance	Allowance + Tolerances	Allowance	Allowance + Tolerances	Average Interference of metal	Average Interference of metal	Average Interference of metal
From	Up to and Including	Mean	+[1]	+[1]	+[1]	+[1]	+[1]	+[1]		+[1]	−[1]	+[1]	−[2]	−[2]	−[2]
0	$\frac{3}{16}$	$\frac{1}{8}$	0.001	0.003	0.0004	0.0018	0.0002	0.0010	0.0000	0.0005	0.0002	0.0003	0.0000	0.0001	0.0001
$\frac{3}{16}$	$\frac{7}{16}$	$\frac{1}{4}$	0.001	0.005	0.0006	0.0022	0.0004	0.0014	0.0000	0.0007	0.0003	0.0004	0.0001	0.0001	0.0003
$\frac{5}{16}$	$\frac{7}{16}$	$\frac{3}{8}$	0.001	0.005	0.0007	0.0025	0.0005	0.0017	0.0000	0.0007	0.0003	0.0004	0.0001	0.0002	0.0004
$\frac{7}{16}$	$\frac{9}{16}$	$\frac{1}{2}$	0.002	0.006	0.0009	0.0029	0.0006	0.0018	0.0000	0.0008	0.0003	0.0005	0.0001	0.0003	0.0005
$\frac{9}{16}$	$\frac{11}{16}$	$\frac{5}{8}$	0.002	0.006	0.0010	0.0032	0.0007	0.0021	0.0000	0.0008	0.0003	0.0005	0.0002	0.0003	0.0006
$\frac{11}{16}$	$\frac{13}{16}$	$\frac{3}{4}$	0.002	0.006	0.0012	0.0036	0.0007	0.0021	0.0000	0.0009	0.0004	0.0005	0.0002	0.0004	0.0008
$\frac{13}{16}$	$\frac{15}{16}$	$\frac{7}{8}$	0.002	0.006	0.0013	0.0037	0.0008	0.0024	0.0000	0.0010	0.0004	0.0006	0.0002	0.0004	0.0009
$\frac{15}{16}$	1 $\frac{1}{16}$	1	0.003	0.009	0.0014	0.0040	0.0009	0.0025	0.0000	0.0010	0.0004	0.0006	0.0003	0.0005	0.0010
1 $\frac{1}{16}$	1 $\frac{3}{16}$	1 $\frac{1}{8}$	0.003	0.009	0.0015	0.0043	0.0010	0.0026	0.0000	0.0010	0.0004	0.0006	0.0003	0.0006	0.0011
1 $\frac{3}{16}$	1 $\frac{3}{8}$	1 $\frac{1}{4}$	0.003	0.009	0.0016	0.0044	0.0010	0.0028	0.0000	0.0010	0.0004	0.0006	0.0003	0.0006	0.0013

$1\frac{3}{8}$	$1\frac{5}{8}$	$1\frac{1}{2}$	0.003	0.009	0.0018	0.0048	0.0012	0.0030	0.0000	0.0012	0.0005	0.0007	0.0004	0.0008	0.0015
$1\frac{5}{8}$	$1\frac{7}{8}$	$1\frac{3}{4}$	0.004	0.010	0.0020	0.0052	0.0013	0.0033	0.0000	0.0012	0.0005	0.0007	0.0004	0.0009	0.0018
$1\frac{7}{8}$	$2\frac{1}{8}$	2	0.004	0.010	0.0022	0.0054	0.0014	0.0034	0.0000	0.0013	0.0005	0.0008	0.0005	0.0010	0.0020
$2\frac{1}{8}$	$2\frac{3}{8}$	$2\frac{1}{4}$	0.004	0.010	0.0024	0.0058	0.0015	0.0035	0.0000	0.0013	0.0005	0.0008	0.0006	0.0011	0.0023
$2\frac{3}{8}$	$2\frac{3}{4}$	$2\frac{1}{2}$	0.005	0.011	0.0026	0.0062	0.0017	0.0039	0.0000	0.0013	0 0005	0.0008	0.0006	0.0013	0.0025
$2\frac{3}{4}$	$3\frac{1}{4}$	3	0.005	0.013	0.0029	0.0067	0.0019	0.0043	0.0000	0.0015	0.0006	0.0009	0.0008	0.0015	0.0030
$3\frac{1}{4}$	$3\frac{3}{4}$	$3\frac{1}{2}$	0.006	0.014	0.0032	0.0072	0.0021	0.0045	0.0000	0.0015	0.0006	0.0009	0.0009	0.0018	0.0035
$3\frac{3}{4}$	$4\frac{1}{4}$	4	0.006	0.014	0.0035	0.0077	0.0023	0.0049	0.0000	0.0016	0.0006	0.0010	0.0010	0.0020	0.0040
$4\frac{1}{4}$	$4\frac{3}{4}$	$4\frac{1}{2}$	0.007	0.015	0.0038	0.0080	0.0025	0.0051	0.0000	0.0017	0.0007	0.0010	0.0011	0.0023	0.0045
$4\frac{3}{4}$	$5\frac{1}{2}$	5	0.007	0.015	0.0041	0.0085	0.0026	0.0054	0.0000	0.0017	0.0007	0.0010	0.0013	0.0025	0.0050
$5\frac{1}{2}$	$6\frac{1}{2}$	6	0.008	0.018	0.0046	0.0094	0.0030	0.0060	0.0000	0.0018	0.0007	0.0011	0.0015	0.0030	0.0060
$6\frac{1}{2}$	$7\frac{1}{2}$	7	0.009	0.019	0.0051	0.0101	0 0033	0.0063	0.0000	0.0019	0.0008	0.0011	0.0018	0.0035	0.0070
$7\frac{1}{2}$	$8\frac{1}{2}$	8	0 010	0.020	0.0056	0.0108	0.0036	0.0068	0.0000	0.0020	0.0008	0 0012	0.0020	0.0040	0.0080

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[1] + denotes clearance or amount of looseness.

[2] Obtained by fitting or selection.

Working Gages.—Gages used by the manufacturer to check the work as it is produced. These gages should not accept any product which the inspection gages will reject.

Classification of Fits

The following classification of fits is recommended:

Loose Fit (Class 1)—Large Allowance.—This fit provides for considerable freedom and embraces certain fits where accuracy is not essential.

EXAMPLES.—Machined fits of agricultural and mining machinery; controlling apparatus for marine work; textile, rubber, candy, and bread machinery; general machinery of a similar grade; some ordnance material.

Free Fit (Class 2)—Liberal Allowance.—For running fits with speeds of 600 revolutions per minute, or over, and journal pressures of 600 pounds per square inch, or over.

EXAMPLES.—Dynamos; engines; many machine-tool parts; and some automotive parts.

Medium Fit (Class 3)—Medium Allowance.—For running fits under 600 revolutions per minute and with journal pressures less than 600 pounds per square inch; also for sliding fits; and the more accurate machine-tool and automotive parts.

Snug Fit (Class 4)—Zero Allowance.—This is the closest fit which can be assembled by hand and necessitates work of considerable precision. It should be used where no perceptible shake is permissible and where moving parts are not intended to move freely under a load.

Wringing Fit (Class 5)—Zero to Negative Allowance.—This is also known as a "tunking fit," and it is practically metal-to-metal. Assembly is usually selective and not interchangeable.

Tight Fit (Class 6)—Slight Negative Allowance.—Light pressure is required to assemble these fits and the parts are more or less permanently assembled, such as the fixed ends of studs for gears, pulleys, rocker arms, etc. These fits are used for drive fits in thin sections or extremely long fits in other sections and also for shrink fits on very light sections. Used in automotive, ordnance, and general machine manufacturing.

Medium Force Fit (Class 7)—Negative Allowance.—Considerable pressure is required to assemble these fits, and the parts are considered permanently assembled. These fits are used in fastening locomotive wheels, car wheels, armatures of dynamos, and motors and crank discs to their axles or shafts. They are also used for shrink fit on medium sections or long fits. These fits are the tightest which are recommended for cast-iron holes or external members, as they stress cast iron to its elastic limit.

Heavy Force and Shrink Fit (Class 8)—Considerable Negative Allowance. These fits are used for steel holes where the metal can be highly stressed without exceeding its elastic limit. These fits cause excessive stress for cast-iron holes. Shrink fits are used where heavy force fits are impractical, as on locomotive wheel tires, heavy crank discs of large engines, etc.

Standard Fits Applied to Interchangeable Manufacture

Interchangeable Assembly.—Machine shop practices are governed largely by the conditions which must be met. These conditions are many and varied. The standard fits specified in Table 3 can be applied to all practices.

Tables 2 to 5 show the limiting sizes of mating parts for interchangeable manufacture.

Using the basic-hole principle on which this report is based, shaft members made to the specifications of one class of fit may be mated with hole members made to the specifications of another class without destroying interchangeability.

Selective Assembly.—When the functional conditions of mating parts become so exacting that they cannot be maintained with the use of reasonable manufacturing tolerances, a practice known as "selective assembly" is often employed. In selective assembly,

(Text continues on page 741)

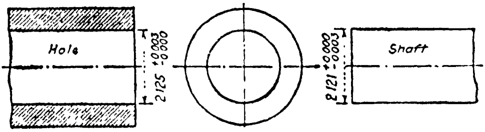
TABLE 4.—LOOSE FIT (CLASS 1)—LARGE ALLOWANCE INTERCHANGEABLE

This fit provides for considerable freedom and embraces certain fits where accuracy is not essential.

(All Dimensions in Inches)

Size			Limits				Tightest Fit	Loosest Fit
From	Up to and Inclusive	Mean	Hole or External Member		Shaft or Internal Member		Allowance	Allowance + Tolerances
			+		−	−	+*	+*
0	3/16	1/8	0.001	0.000	0.001	0.002	0.001	0.003
3/16	5/16	1/4	0.002	0.000	0.001	0.003	0.001	0.005
5/16	7/16	3/8	0.002	0.000	0.001	0.003	0.001	0.005
7/16	9/16	1/2	0.002	0.000	0.002	0.004	0.002	0.006
9/16	11/16	5/8	0.002	0.000	0.002	0.004	0.002	0.006
11/16	13/16	3/4	0.002	0.000	0.002	0.004	0.002	0.006
13/16	15/16	7/8	0.002	0.000	0.002	0.004	0.002	0.006
15/16	1 1/16	1	0.003	0.000	0.003	0.006	0.003	0.009
1 1/16	1 3/16	1 1/8	0.003	0.000	0.003	0.006	0.003	0.009
1 3/16	1 3/8	1 1/4	0.003	0.000	0.003	0.006	0.003	0.009
1 3/8	1 5/8	1 1/2	0.003	0.000	0.003	0.006	0.003	0.009
1 5/8	1 7/8	1 3/4	0.003	0.000	0.004	0.007	0.004	0.010
1 7/8	2 1/8	2	0.003	0.000	0.004	0.007	0.004	0.010
2 1/8	2 3/8	2 1/4	0.003	0.000	0.004	0.007	0.004	0.010
2 3/8	2 3/4	2 1/2	0.003	0.000	0.005	0.008	0.005	0.011
2 3/4	3 1/4	3	0.004	0.000	0.005	0.009	0.005	0.013
3 1/4	3 3/4	3 1/2	0.004	0.000	0.006	0.010	0.006	0.014
3 3/4	4 1/4	4	0.004	0.000	0.006	0.010	0.006	0.014
4 1/4	4 3/4	4 1/2	0.004	0.000	0.007	0.011	0.007	0.015
4 3/4	5 1/2	5	0.004	0.000	0.007	0.011	0.007	0.015
5 1/2	6 1/2	6	0.005	0.000	0.008	0.013	0.008	0.018
6 1/2	7 1/2	7	0.005	0.000	0.009	0.014	0.009	0.019
7 1/2	8 1/2	8	0.005	0.000	0.010	0.015	0.010	0.020

*NOTE: + denotes clearance or amount of looseness.



SUMMARY OF DATA

	Hole	Shaft	
Tightest fit	2.125	2.121	0.004 Allowance
Loosest fit	2.128	2.118	0.010 Allowance + Tolerances

FORMULAS

When d = mean size,

$$\text{Hole tolerance} = 0.0025\sqrt[3]{d}$$

$$\text{Shaft tolerance} = 0.0025\sqrt[3]{d}$$

$$\text{Allowance} = 0.0025\sqrt[3]{d^2}$$

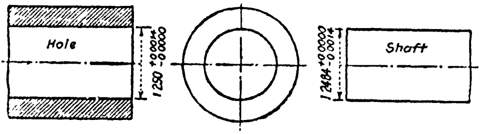
TABLE 5.—FREE FIT (CLASS 2)—LIBERAL ALLOWANCE INTERCHANGEABLE

For running fits with speeds of 600 r.p.m. or over, and journal pressures of 600 pounds per square inch or over.

(All Dimensions in Inches)

Size			Limits				Tightest Fit	Loosest Fit
From	Up to and Inclusive	Mean	Hole or External Member		Shaft or Internal Member		Allowance	Allowance + Tolerances
			+		−	−	+*	+*
0	3/16	1/8	0.0007	0 0000	0.0004	0.0011	0.0004	0.0018
3/16	5/16	1/4	0 0008	0.0000	0.0006	0.0014	0.0006	0.0022
5/16	7/16	3/8	0.0009	0.0000	0.0007	0.0016	0.0007	0.0025
7/16	9/16	1/2	0.0010	0.0000	0.0009	0.0019	0.0009	0.0029
9/16	11/16	5/8	0.0011	0 0000	0.0010	0.0021	0.0010	0.0032
11/16	13/16	3/4	0.0012	0.0000	0.0012	0.0024	0.0012	0.0036
13/16	15/16	7/8	0.0012	0.0000	0.0013	0.0025	0.0013	0.0037
15/16	1 1/16	1	0.0013	0.0000	0.0014	0.0027	0.0014	0.0040
1 1/16	1 3/16	1 1/8	0.0014	0 0000	0.0015	0.0029	0 0015	0.0043
1 3/16	1 3/8	1 1/4	0.0014	0.0000	0.0016	0 0030	0.0016	0.0044
1 3/8	1 5/8	1 1/2	0 0015	0.0000	0.0018	0 0033	0 0018	0.0048
1 5/8	1 7/8	1 3/4	0.0016	0.0000	0.0020	0.0036	0.0020	0.0052
1 7/8	2 1/8	2	0.0016	0.0000	0.0022	0 0038	0.0022	0.0054
2 1/8	2 3/8	2 1/4	0.0017	0.0000	0.0024	0.0041	0.0024	0.0058
2 3/8	2 3/4	2 1/2	0.0018	0.0000	0.0026	0.0044	0.0026	0.0062
2 3/4	3 1/4	3	0.0019	0.0000	0.0029	0.0048	0.0029	0.0067
3 1/4	3 3/4	3 1/2	0.0020	0.0000	0.0032	0.0052	0.0032	0.0072
3 3/4	4 1/4	4	0.0021	0.0000	0.0035	0.0056	0.0035	0.0077
4 1/4	4 3/4	4 1/2	0.0021	0.0000	0.0038	0.0059	0.0038	0.0080
4 3/4	5 1/2	5	0.0022	0.0000	0.0041	0.0063	0.0041	0.0085
5 1/2	6 1/2	6	0.0024	0.0000	0.0046	0.0070	0.0046	0.0094
6 1/2	7 1/2	7	0.0025	0.0000	0.0051	0.0076	0.0051	0.0101
7 1/2	8 1/2	8	0.0026	0.0000	0.0056	0.0082	0.0056	0.0108

*NOTE: + denotes clearances or amount of looseness.



SUMMARY OF DATA

	Hole	Shaft	
Tightest fit....................	1.2500	1.2484	0.0016 Allowance
Loosest fit.....................	1.2514	1.2470	0.0044 Allowance + Tolerances

FORMULAS

When d = mean size,

Hole tolerance $= 0.0013\sqrt[3]{d}$

Shaft tolerance $= 0.0013\sqrt[3]{d}$

Allowance $= 0.0014\sqrt[3]{d^2}$

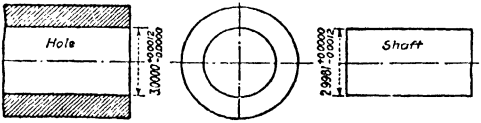
TABLE 6.—MEDIUM FIT (CLASS 3)—MEDIUM ALLOWANCE INTERCHANGEABLE

For running fits under 600 r.p.m. and with journal pressures less than 600 pounds per square inch; also for sliding fits, and the more accurate machine-tool and automotive parts.

(All Dimensions in Inches)

Size			Limits				Tightest Fit	Loosest Fit
From	Up to and Inclusive	Mean	Hole or External Member		Shaft or Internal Member		Allowance	Allowance + Tolerances
			+		–	–	+*	+*
0	3/16	1/8	0.0004	0.0000	0.0002	0.0006	0.0002	0.0010
3/16	5/16	1/4	0.0005	0.0000	0.0004	0.0009	0.0004	0.0014
5/16	7/16	3/8	0.0006	0.0000	0.0005	0.0011	0.0005	0.0017
7/16	9/16	1/2	0.0006	0.0000	0.0006	0.0012	0.0006	0.0018
9/16	11/16	5/8	0.0007	0.0000	0.0007	0.0014	0.0007	0.0021
11/16	13/16	3/4	0.0007	0.0000	0.0007	0.0014	0.0007	0.0021
13/16	15/16	7/8	0.0008	0.0000	0.0008	0.0016	0.0008	0.0024
15/16	1 1/16	1	0.0008	0.0000	0.0009	0.0017	0.0009	0.0025
1 1/16	1 3/16	1 1/8	0.0008	0.0000	0.0010	0.0018	0.0010	0.0026
1 3/16	1 3/8	1 1/4	0.0009	0.0000	0.0010	0.0019	0.0010	0.0028
1 3/8	1 5/8	1 1/2	0.0009	0.0000	0.0012	0.0021	0.0012	0.0030
1 5/8	1 7/8	1 3/4	0.0010	0.0000	0.0013	0.0023	0.0013	0.0033
1 7/8	2 1/8	2	0.0010	0.0000	0.0014	0.0024	0.0014	0.0034
2 1/8	2 3/8	2 1/4	0.0010	0.0000	0.0015	0.0025	0.0015	0.0035
2 3/8	2 3/4	2 1/2	0.0011	0.0000	0.0017	0.0028	0.0017	0.0039
2 3/4	3 1/4	3	0.0012	0.0000	0.0019	0.0031	0.0019	0.0043
3 1/4	3 3/4	3 1/2	0.0012	0.0000	0.0021	0.0033	0.0021	0.0045
3 3/4	4 1/4	4	0.0013	0.0000	0.0023	0.0036	0.0023	0.0049
4 1/4	4 3/4	4 1/2	0.0013	0.0000	0.0025	0.0038	0.0025	0.0051
4 3/4	5 1/2	5	0.0014	0.0000	0.0026	0.0040	0.0026	0.0054
5 1/2	6 1/2	6	0.0015	0.0000	0.0030	0.0045	0.0030	0.0060
6 1/2	7 1/2	7	0.0015	0.0000	0.0033	0.0048	0.0033	0.0063
7 1/2	8 1/2	8	0.0016	0.0000	0.0036	0.0052	0.0036	0.0068

*NOTE: + denotes clearance or amount of looseness.



SUMMARY OF DATA

	Hole	Shaft	
Tightest fit....................	3.0000	2.9981	0.0019 Allowance
Loosest fit.....................	3.0012	2.9969	0.0043 Allowance + Tolerances

FORMULAS

When d = mean size,

Hole tolerance $= 0.0008\sqrt[3]{d}$

Shaft tolerance $= 0.0008\sqrt[3]{d}$

Allowance $= 0.0009\sqrt[3]{d^2}$

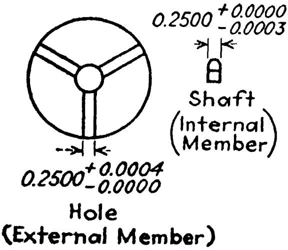
TABLE 7.—SNUG FIT (CLASS 4)—ZERO ALLOWANCE INTERCHANGEABLE

This is the closest fit which can be assembled by hand and necessitates work of considerable precision. It should be used where no perceptible shake is permissible and where moving parts are not intended to move freely under load.

(All Dimensions in Inches)

Size			Limits				Tightest Fit	Loosest Fit
From	Up to and Inclusive	Mean	Hole or External Member		Shaft or Internal Member		Allowance	Allowance + Tolerances
			+			−		+*
0	3/16	1/8	0.0003	0.0000	0.0000	0.0002	0.0000	0.0005
3/16	5/16	1/4	0.0004	0.0000	0.0000	0.0003	0.0000	0.0007
5/16	7/16	3/8	0.0004	0.0000	0.0000	0.0003	0.0000	0.0007
7/16	9/16	1/2	0.0005	0.0000	0.0000	0.0003	0.0000	0.0008
9/16	11/16	5/8	0.0005	0.0000	0.0000	0.0003	0.0000	0.0008
11/16	13/16	3/4	0.0005	0.0000	0.0000	0.0004	0.0000	0.0009
13/16	15/16	7/8	0.0006	0.0000	0.0000	0.0004	0.0000	0.0010
15/16	1 1/16	1	0.0006	0.0000	0.0000	0.0004	0.0000	0.0010
1 1/16	1 3/16	1 1/8	0.0006	0.0000	0.0000	0.0004	0.0000	0.0010
1 3/16	1 3/8	1 1/4	0.0006	0.0000	0.0000	0.0004	0.0000	0.0010
1 3/8	1 5/8	1 1/2	0.0007	0.0000	0.0000	0.0005	0.0000	0.0012
1 5/8	1 7/8	1 3/4	0.0007	0.0000	0.0000	0.0005	0.0000	0.0012
1 7/8	2 1/8	2	0.0008	0.0000	0.0000	0.0005	0.0000	0.0013
2 1/8	2 3/8	2 1/4	0.0008	0.0000	0.0000	0.0005	0.0000	0.0013
2 3/8	2 3/4	2 1/2	0.0008	0.0000	0.0000	0.0005	0.0000	0.0013
2 3/4	3 1/4	3	0.0009	0.0000	0.0000	0.0006	0.0000	0.0015
3 1/4	3 3/4	3 1/2	0.0009	0.0000	0.0000	0.0006	0.0000	0.0015
3 3/4	4 1/4	4	0.0010	0.0000	0.0000	0.0006	0.0000	0.0016
4 1/4	4 3/4	4 1/2	0.0010	0.0000	0.0000	0.0007	0.0000	0.0017
4 3/4	5 1/2	5	0.0010	0.0000	0.0000	0.0007	0.0000	0.0017
5 1/2	6 1/2	6	0.0011	0.0000	0.0000	0.0007	0.0000	0.0018
6 1/2	7 1/2	7	0.0011	0.0000	0.0000	0.0008	0.0000	0.0019
7 1/2	8 1/2	8	0.0012	0.0000	0.0000	0.0008	0.0000	0.0020

* NOTE: + denotes clearance or amount of looseness.



SUMMARY OF DIMENSIONS

	Hole	Shaft	
Tightest fit....	0.2500	0.2500	0.0000 Allowance
Loosest fit.....	0.2504	0.2497	0.0007 Allowance + Tolerances

FORMULAS

When d = mean size,

Hole tolerance = $0.0006\sqrt[3]{d}$.

Shaft tolerance = $0.0004\sqrt[3]{d}$.

Allowance = 0.0000.

TABLE 8.—WRINGING FIT (CLASS 5)—ZERO TO NEGATIVE ALLOWANCE SELECTIVE ASSEMBLY

This is also known as a "tunking fit" and it is practically metal-to-metal. Assembly is usually selective and not interchangeable. (All Dimensions in Inches)

Size			Limits				Tightest Fit	Loosest Fit	Selected Fit
From	Up to and Inclusive	Mean	Hole or External Member		Shaft or Internal Member		Allowance	Allowance + Tolerances	Average Interference of metal
			+		+		—*	+*	
0	3/16	1/8	0.0003	0.0000	0.0002	0.0000	0.0002	0.0003	0.0000
3/16	5/16	1/4	0.0004	0.0000	0.0003	0.0000	0.0003	0.0004	0.0000
5/16	7/16	3/8	0.0004	0.0000	0.0003	0.0000	0.0003	0.0004	0.0000
7/16	9/16	1/2	0.0005	0.0000	0.0003	0.0000	0.0003	0.0005	0.0000
9/16	11/16	5/8	0.0005	0.0000	0.0003	0.0000	0.0003	0.0005	0.0000
11/16	13/16	3/4	0.0005	0.0000	0.0004	0.0000	0.0004	0.0005	0.0000
13/16	15/16	7/8	0.0006	0.0000	0.0004	0.0000	0.0004	0.0006	0.0000
15/16	1 1/16	1	0.0006	0.0000	0.0004	0.0000	0.0004	0.0006	0.0000
1 1/16	1 3/16	1 1/8	0.0006	0.0000	0.0004	0.0000	0.0004	0.0006	0.0000
1 3/16	1 3/8	1 1/4	0.0006	0.0000	0.0004	0.0000	0.0004	0.0006	0.0000
1 3/8	1 5/8	1 1/2	0.0007	0.0000	0.0005	0.0000	0.0005	0.0007	0.0000
1 5/8	1 7/8	1 3/4	0.0007	0.0000	0.0005	0.0000	0.0005	0.0007	0.0000
1 7/8	2 1/8	2	0.0008	0.0000	0.0005	0.0000	0.0005	0.0008	0.0000
2 1/8	2 3/8	2 1/4	0.0008	0.0000	0.0005	0.0000	0.0005	0.0008	0.0000
2 3/8	2 3/4	2 1/2	0.0008	0.0000	0.0005	0.0000	0.0005	0.0008	0.0000
2 3/4	3 1/4	3	0.0009	0.0000	0.0006	0.0000	0.0006	0.0009	0.0000
3 1/4	3 3/4	3 1/2	0.0009	0.0000	0.0006	0.0000	0.0006	0.0009	0.0000
3 3/4	4 1/4	4	0.0010	0.0000	0.0006	0.0000	0.0006	0.0010	0.0000
4 1/4	4 3/4	4 1/2	0.0010	0.0000	0.0007	0.0000	0.0007	0.0010	0.0000
4 3/4	5 1/2	5	0.0010	0.0000	0.0007	0.0000	0.0007	0.0010	0.0000
5 1/2	6 1/2	6	0.0011	0.0000	0.0007	0.0000	0.0007	0.0011	0.0000
6 1/2	7 1/2	7	0.0011	0.0000	0.0008	0.0000	0.0008	0.0011	0.0000
7 1/2	8 1/2	8	0.0012	0.0000	0.0008	0.0000	0.0008	0.0012	0.0000

* NOTE.—— denotes interference of metal or negative allowance; + denotes clearance or amount of looseness.

SUMMARY OF DIMENSIONS

	Hole	Shaft	
Tightest fit..	0.6250	0.6253	−0.0003
Loosest fit ..	0.6255	0.6250	+0.0005
Selected fit..	0.6250	0.6250	0.0000

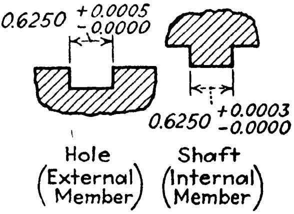
FORMULAS

When d = mean size.

Hole tolerance = $0.0006\sqrt[3]{d}$.

Shaft tolerance = $0.0004\sqrt[3]{d}$.

Average interference of metal = 0.0000.



The average interference of metal is the desired condition and must be obtained by selective assembly, that is, by mating large shafts in large holes and small shafts in small holes.

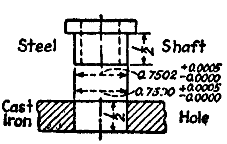
TABLE 9.—TIGHT FIT (CLASS 6)—SLIGHT NEGATIVE ALLOWANCE SELECTIVE ASSEMBLY

Light pressure is required to assemble these fits and the parts are more or less permanently assembled, such as the fixed ends of studs for gears, pulleys, rocker arms, etc. These fits are used for drive fits in thin sections or extremely long fits in other sections, and also for shrink fits on very light sections. Used in automotive, ordnance and general machine manufacturing.

(All Dimensions in Inches)

Size			Limits				Tightest Fit	Loosest Fit	Selected Fit
From	Up to and Inclusive	Mean	Hole or External Member		Shaft or Internal Member		Allowance	Allowance + Tolerances	Average Interference of metal
			+		+	+	−*	*	−*
0	3/16	1/8	0.0003	0.0000	0.0003	0.0000	0.0003	+0.0003	0.0000
3/16	5/16	1/4	0.0004	0.0000	0.0005	0.0001	0.0005	+0.0003	0.0001
5/16	7/16	3/8	0.0004	0.0000	0.0005	0.0001	0.0005	+0.0003	0.0001
7/16	9/16	1/2	0.0005	0.0000	0.0006	0.0001	0.0006	+0.0004	0.0001
9/16	11/16	5/8	0.0005	0.0000	0.0007	0.0002	0.0007	+0.0003	0.0002
11/16	13/16	3/4	0.0005	0.0000	0.0007	0.0002	0.0007	+0.0003	0.0002
13/16	15/16	7/8	0.0006	0.0000	0.0008	0.0002	0.0008	+0.0004	0.0002
15/16	1 1/16	1	0.0006	0.0000	0.0009	0.0003	0.0009	+0.0003	0.0003
1 1/16	1 3/16	1 1/8	0.0006	0.0000	0.0009	0.0003	0.0009	+0.0003	0.0003
1 3/16	1 3/8	1 1/4	0 0006	0.0000	0.0009	0.0003	0.0009	+0.0003	0.0003
1 3/8	1 5/8	1 1/2	0.0007	0.0000	0.0011	0.0004	0.0011	+0.0003	0.0004
1 5/8	1 7/8	1 3/4	0.0007	0.0000	0.0011	0.0004	0.0011	+0.0003	0.0004
1 7/8	2 1/8	2	0.0008	0.0000	0.0013	0.0005	0.0013	+0.0003	0.0005
2 1/8	2 3/8	2 1/4	0.0008	0.0000	0.0014	0.0006	0.0014	+0.0002	0.0006
2 3/8	2 3/4	2 1/2	0.0008	0.0000	0.0014	0.0006	0.0014	+0.0002	0.0006
2 3/4	3 1/4	3	0.0009	0.0000	0.0017	0.0008	0.0017	+0.0001	0.0008
3 1/4	3 3/4	3 1/2	0.0009	0.0000	0.0018	0.0009	0.0018	−0.0000	0.0009
3 3/4	4 1/4	4	0.0010	0.0000	0.0020	0.0010	0.0020	−0.0000	0.0010
4 1/4	4 3/4	4 1/2	0.0010	0.0000	0.0021	0.0011	0.0021	−0.0001	0.0011
4 3/4	5 1/2	5	0.0010	0.0000	0.0023	0.0013	0.0023	−0.0003	0 0013
5 1/2	6 1/2	6	0.0011	0.0000	0.0026	0.0015	0.0026	−0.0004	0.0015
6 1/2	7 1/2	7	0.0011	0.0000	0.0029	0.0018	0.0029	−0.0007	0.0018
7 1/2	8 1/2	8	0.0012	0.0000	0.0032	0.0020	0.0032	−0.0008	0.0020

* NOTE.—− denotes interference of metal or negative allowance. + denotes clearance or amount of looseness.



SUMMARY OF DIMENSIONS

	Hole	Shaft	
Tightest fit	0.7500	0.7507	−0.0007
Loosest fit	0.7505	0.7502	+0.0003
†Selected fit	0.7500	0.7502	−0.0002
‡Selected fit	0.7505	0.7507	−0.0002

Hole stress = 2,608 pounds per square inch.
Force for pressing = 1/2 × 0.149 = 0.075 ton
†Small shaft in small hole.
‡Large shaft in large hole.

Mean Size	Interference of Metal per Inch of Mean Size, Inches			Greatest Hole Stress, Steel Shaft in						Force for Pressing Steel Shaft into					
				Steel Hole, Pounds per Square Foot			Cast-Iron Hole, Pounds per Square Foot			Steel Hole, Tons			Cast-Iron Hole, Tons		
	Tightest Fit	Loosest Fit	Selected Fit	Tightest Fit	Loosest Fit	Selected Fit	Tightest Fit	Loosest Fit	Selected Fit	Tightest Fit	Loosest Fit	Selected Fit	Tightest Fit	Loosest Fit	Selected Fit
1/8	0.00240	No values, due to smallest shaft member in largest hole member	0.00025	69,600	No values, due to smallest shaft member in largest hole member	7,250	25,037	No values, due to smallest shaft member in largest hole member	2,608	0.389	No values, due to smallest shaft member in largest hole member	0 000	0.224	No values, due to smallest shaft member in largest hole member	0.000
1/4	0.00200		0.00025	58,000		7,250	20,864		2,608	0 649		0.130	0 374		0.075
3/8	0.00133		0.00025	38,700		7,250	13,909		2,608	0.649		0.130	0.374		0.075
1/2	0.00120		0.00025	34,800		7,250	12,518		2,608	0.779		0.130	0.448		0.075
5/8	0.00112		0.00025	32,480		7,250	11,684		2,608	0.909		0.260	0.523		0.149
3/4	0.00093		0.00025	27,100		7,250	9,737		2,608	0.909		0.260	0.523		0.149
7/8	0.00091		0.00025	26,500		7,250	9,538		2,608	1.038		0.260	0.598		0.149
1	0.00090		0.00025	26,100		7,250	9,389		2,608	1 168		0.389	0.672		0.224
1 1/8	0 00080		0 00025	23,200		7,250	8,346		2,608	1.168		0.389	0.672		0.224
1 1/4	0.00072		0.00025	20,880		7,250	7,511		2,608	1.168		0.389	0 672		0.224
1 1/2	0.00073		0.00025	21,300		7,250	7,650		2,608	1 428		0.519	0.822		0.299
1 3/4	0.00063		0.00025	18,240		7,250	6,557		2,608	1.428		0.519	0.822		0.299
2	0.00065		0.00025	18,850		7,250	6,781		2,608	1.687		0.649	0.971		0.374
2 1/4	0.00062		0.00025	18,040		7,250	6,491		2,608	1.817		0.779	1.046		0.448
2 1/2	0.00056		0.00025	16,200		7,250	5,842		2,608	1.817		0.779	1.046		0.448
3	0.00057		0.00025	16,433		7,250	5,911		2,608	2.207		1.038	1.270		0.598
3 1/2	0.00051		0.00025	14,910		7,250	5,365		2,608	2.336		1.168	1.345		0.672
4	0.00050		0.00025	14,500		7,250	5,216		2,608	2.596		1.298	1.494		0.747
4 1/2	0.00047	0.00002	0 00025	13,530	644	7,250	4,868	232	2,608	2.726	0.130	1.428	1.569	0.075	0.822
5	0.00046	0.00006	0.00025	13,340	1,740	7,250	4.799	625	2,608	2.985	0.389	1.687	1.719	0.224	0.971
6	0.00043	0.00007	0.00025	12,570	1,933	7,250	4,521	695	2,608	3.375	0.519	1.947	1.942	0.299	1.121
7	0.00041	0 00010	0.00025	12,010	2,900	7,250	4,322	1,043	2,608	3.764	0.909	2.336	2.167	0.523	1.345
8	0.00040	0.00010	0.00025	11,600	2,900	7,250	4,173	1,043	2,608	4.154	1.038	2 596	2.391	0.598	1.494
				Stress = 29,000,000A/d			Stress = 10,432,000A/d			Force = 1,298 A			Force = 747.2 A		

A = allowance, d = mean size. Values for stress and force are true only when hub diameter equals twice the hole diameter. The force values are for fit 1 inch long. For other lengths multiply by the length of fit in inches.

The values of greatest hole stress are for a mean diameter sizes only. For other sizes in a step, the interference per inch of diameter and hence the greatest hole stress will vary from the values given in the table by less than 10 per cent.

TABLE 11.—MEDIUM FORCE FIT (CLASS 7)—NEGATIVE ALLOWANCE SELECTIVE ASSEMBLY

Considerable pressure is required to assemble these fits and the parts are considered permanently assembled. These fits are used in fastening locomotive wheels, car wheels, armatures of dynamos and motors, and crank disks to their axles or shafts. They are also used for shrink fits on medium sections or long fits. These fits are the tightest which are recommended for cast-iron holes or external members as they stress cast iron to its elastic limit.

(All Dimensions in Inches.)

Size			Limit				Tightest Fit	Loosest Fit	Selected Fit
From	Up to and Inclusive	Mean	Hole or External Member		Shaft or Internal Member		Allowance	Allowance + Tolerances	Average Interference of metal
			+		+	+	— *	*	— *
0	3/16	1/8	0.0003	0.0000	0.0004	0.0001	0.0004	+0.0002	0.0001
3/16	5/16	1/4	0.0004	0.0000	0.0005	0.0001	0.0005	+0.0003	0.0001
5/16	7/16	3/8	0.0004	0.0000	0.0006	0.0002	0.0006	+0.0002	0.0002
7/16	9/16	1/2	0.0005	0.0000	0.0008	0.0003	0.0008	+0.0002	0.0003
9/16	11/16	5/8	0.0005	0.0000	0.0008	0.0003	0.0008	+0.0002	0.0003
11/16	13/16	3/4	0.0005	0.0000	0.0009	0.0004	0.0009	+0.0001	0.0004
13/16	15/16	7/8	0.0006	0.0000	0.0010	0.0004	0.0010	+0.0002	0.0004
15/16	1 1/16	1	0.0006	0.0000	0.0011	0.0005	0.0011	+0.0001	0.0005
1 1/16	1 3/16	1 1/8	0.0006	0.0000	0.0012	0.0006	0.0012	0.0000	0.0006
1 3/16	1 3/8	1 1/4	0.0006	0.0000	0.0012	0.0006	0.0012	0.0000	0.0006
1 3/8	1 5/8	1 1/2	0.0007	0.0000	0.0015	0.0008	0.0015	−0.0001	0.0008
1 5/8	1 7/8	1 3/4	0.0007	0.0000	0.0016	0.0009	0.0016	−0.0002	0.0009
1 7/8	2 1/8	2	0.0008	0.0000	0.0018	0.0010	0.0018	−0.0002	0.0010
2 1/8	2 3/8	2 1/4	0.0008	0.0000	0.0019	0.0011	0.0019	−0.0003	0.0011
2 3/8	2 3/4	2 1/2	0.0008	0.0000	0.0021	0.0013	0.0021	−0.0005	0.0013
2 3/4	3 1/4	3	0.0009	0.0000	0.0024	0.0015	0.0024	−0.0006	0.0015
3 1/4	3 3/4	3 1/2	0.0009	0.0000	0.0027	0.0018	0.0027	−0.0009	0.0018
3 3/4	4 1/4	4	0.0010	0.0000	0.0030	0.0020	0.0030	−0.0010	0.0020
4 1/4	4 3/4	4 1/2	0.0010	0.0000	0.0033	0.0023	0.0033	−0.0013	0.0023
4 3/4	5 1/2	5	0.0010	0.0000	0.0035	0.0025	0.0035	−0.0015	0.0025
5 1/2	6 1/2	6	0.0011	0.0000	0.0041	0.0030	0.0041	−0.0019	0.0030
6 1/2	7 1/2	7	0.0011	0.0000	0.0046	0.0035	0.0046	−0.0024	0.0035
7 1/2	8 1/2	8	0.0012	0.0000	0.0052	0.0040	0.0052	−0.0028	0.0040
8 1/2	9 1/2	9	0.0012	0.0000	0.0057	0.0045	0.0057	−0.0033	0.0045
10 1/2	11 1/2	10	0.0013	0.0000	0.0063	0.0050	0.0063	−0.0037	0.0050
11 1/2	13	12	0.0014	0.0000	0.0074	0.0060	0.0074	0.0046	0.0060
13	15	14	0.0014	0.0000	0.0084	0.0070	0.0084	−0.0056	0.0070
15	17	16	0.0015	0.0000	0.0095	0.0080	0.0095	−0.0065	0.0080
17	19	18	0.0016	0.0000	0.0106	0.0090	0.0106	−0.0074	0.0090
19	22	20	0.0016	0.0000	0.0116	0.0100	0.0116	−0.0084	0.0100
22	26	24	0.0017	0.0000	0.0137	0.0120	0.0137	−0.0103	0.0120
26	30	28	0.0018	0.0000	0.0158	0.0140	0.0158	−0.0122	0.0140
30	34	32	0.0019	0.0000	0.0179	0.0160	0.0179	−0.0141	0.0160
34	38	36	0.0020	0.0000	0.0200	0.0180	0.0200	−0.0160	0.0180
38	44	40	0.0021	0.0000	0.0221	0.0200	0.0221	−0.0179	0.0200
44	52	48	0.0022	0.0000	0.0262	0.0240	0.0262	−0.0218	0.0240
52	60	56	0.0023	0.0000	0.0303	0.0280	0.0303	−0.0257	0.0280
60	68	64	0.0024	0.0000	0.0344	0.0320	0.0344	−0.0296	0.0320
68	76	72	0.0025	0.0000	0.0385	0.0360	0.0385	−0.0335	0.0360
76	88	80	0.0026	0.0000	0.0426	0.0400	0.0426	−0.0374	0.0400
88	104	96	0.0027	0.0000	0.0507	0.0480	0.0507	−0.0453	0.0480
104	120	112	0.0029	0.0000	0.0589	0.0560	0.0589	−0.0531	0.0560
120	136	128	0.0030	0.0000	0.0670	0.0640	0.0670	−0.0610	0.0640

* NOTE.—— denotes interference of metal or negative allowance. + denotes clearance or amount of looseness.

attainable manufacturing tolerances are established, then the completed parts are sorted or mated according to size so as to maintain the required functional conditions. The productive processes here are the same as those for interchangeable manufacturing, with the addition of a sorting or mating operation before assembly.

Tables 8 to 14 show the limiting sizes for the manufacture of mating parts which are to be assembled by selection.

SUMMARY OF DIMENSIONS

	Hole	Shaft	
Tightest fit	56 0000	56 0583	−0.0583
Loosest fit	56 0023	56.0560	−0.0537
†Selected fit	56 0000	56.0560	−0.0560
‡Selected fit	56 0023	56.0583	−0.0560

Hole stress = 29,000 pounds per square inch.

†Small shaft in small hole.

‡ Large shaft in large hole.

FORMULAS

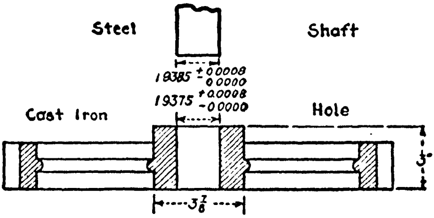
When d = mean size.

$$\text{Hole tolerance} = 0.0006\sqrt[3]{d}.$$
$$\text{Shaft tolerance} = 0.0006\sqrt[3]{d}.$$

Average interference of metal = $0.001d$.

The average interference of metal given is the desired condition and must be obtained by selective assembly, that is, by mating large shafts in large holes and small shafts in small holes.

For hole and shaft tolerances, the same formulas were used for sizes larger than 8 inches, although there were no data available for these diameters.



SUMMARY OF DIMENSIONS

	Hole	Shaft	
Tightest fit	1 9375	1 9393	−0.0018
Loosest fit	1 9383	1.9385	−0.0002
Selected fit	1 9375	1 9385	−0.0010
Selected fit	1 9383	1.9393	−0.0010

Hole stress = 5,216 pounds per square inch.

Force for pressing = 3 × 0.747 = 2.241 tons.

FORMULAS

When d = mean size.

$$\text{Hole tolerance} = 0.0006.$$
$$\text{Shaft tolerance} = 0.0006\sqrt[3]{d}.$$

Average interference of metal = $0.0005d$.

The average interference of metal given is the desired condition and must be obtained by selective assembly, that is, by mating large shafts in large holes and small shafts in small holes.

For hole and shaft tolerances, the same formulas were used for sizes larger than 8 inches, although no data were available for these diameters.

TABLE 12.—MEDIUM FORCE FIT (CLASS 7)—NEGATIVE ALLOWANCE SELECTIVE ASSEMBLY

Mean Size	Interference of Metal per inch of Mean Size, Inches			Greatest Hole Stress, Steel Shaft in						Force for Pressing Steel Shaft into					
				Steel Hole, Pounds per Square Inch			Cast Iron Hole, Pounds per Square Inch			Steel Hole, Tons			Cast Iron Hole, Tons		
	Tightest Fit	Loosest Fit	Selected Fit	Tightest Fit	Loosest Fit	Selected Fit	Tightest Fit	Loosest Fit	Selected Fit	Tightest Fit	Loosest Fit	Selected Fit	Tightest Fit	Loosest Fit	Selected Fit
1/8	0.00320	*	0.0005	92,800	*	14,500	33,382	*	5,216	0.519	*	0.130	0.299	*	0.075
1/4	0.00200	*	0.0005	58,000	*	14,500	20,864	*	5,216	0.649	*	0.130	0.374	*	0.075
3/8	0.00160	*	0.0005	46,400	*	14,500	16,691	*	5,216	0.779	*	0.260	0.448	*	0.149
1/2	0.00160	*	0.0005	46,400	*	14,500	16,691	*	5,216	1.038	*	0.389	0.598	*	0.224
5/8	0.00128	*	0.0005	37,120	*	14,500	13,353	*	5,216	1.038	*	0.389	0.598	*	0.224
3/4	0.00120	*	0.0005	34,800	*	14,500	12,513	*	5,216	1.168	*	0.519	0.672	*	0.299
7/8	0.00114	*	0.0005	33,140	*	14,500	11,922	*	5,216	1.298	*	0.519	0.747	*	0.299
1	0.00110	*	0.0005	31,900	*	14,500	11,475	*	5,216	1.428	*	0.649	0.822	*	0.374
1 1/8	0.00107	*	0.0005	30,930	*	14,500	11,127	*	5,216	1.558	*	0.779	0.897	*	0.448
1 1/4	0.00096	*	0.0005	27,830	*	14,500	10,015	*	5,216	1.558	*	0.779	0.897	*	0.448
1 3/8	0.00100	0.00007	0.0005	29,000	1,934	14,500	10,432	695	5,216	1.947	0.130	1.038	1.121	0.075	0.598
1 1/2	0.00091	0.00011	0.0005	26,510	3,314	14,500	9,538	1,192	5,216	2.077	0.260	1.168	1.196	0.149	0.672
2	0.00090	0.00010	0.0005	26,100	2,900	14,500	9,389	1,043	5,216	2.336	0.260	1.298	1.345	0.149	0.747
2 1/4	0.00084	0.00013	0.0005	24,490	3,866	14,500	8,809	1,391	5,216	2.466	0.389	1.428	1.420	0.224	0.822
2 1/2	0.00084	0.00020	0.0005	24,340	5,800	14,500	8,763	2,086	5,216	2.726	0.649	1.687	1.569	0.373	0.971
3	0.00080	0.00020	0.0005	23,200	5,800	14,500	8,346	2,086	5,216	3.115	0.779	1.947	1.793	0.448	1.121
3 1/2	0.00077	0.00026	0.0005	22,370	7,457	14,500	8,048	2,682	5,216	3.505	1.168	2.336	2.017	0.672	1.345
4	0.00075	0.00025	0.0005	21,750	7,250	14,500	7,824	2,608	5,216	3.894	1.298	2.596	2.242	0.747	1.494
4 1/2	0.00073	0.00029	0.0005	21,270	8,377	14,500	7,652	3,014	5,216	4.283	1.687	2.985	2.466	0.971	1.719
5	0.00070	0.00030	0.0005	20,300	8,700	14,500	7,302	3,130	5,216	4.543	1.947	3.245	2.615	1.121	1.868
6	0.00068	0.00032	0.0005	19,810	9,183	14,500	7,129	3,303	5,216	5.322	2.466	3.894	3.064	1.420	2.242
7	0.00066	0.00034	0.0005	19,060	9,942	14,500	0,855	3,577	5,216	5.971	3.115	4.543	3.437	1.793	2.615

8	0.00065	0.00035	0.0005	18,850	10,150	14,500	6,781	3,651	5,216	6.759	3.634	5.192	3.885	2.092	2.989
9	0.00063	0.00037	0.0005	18,370	10,630	14,500	6,607	3,875	5,216	7.399	4.283	5.841	4.259	2.466	3.362
10	0.00063	0.00037	0.0005	18,270	10,730	14,500	6,572	3,860	5,216	8.177	4.803	6.490	4.707	2.765	3.736
12	0.00062	0.00038	0.0005	17,890	11,120	14,500	6,433	3,999	5,216	9.605	5.971	7.788	5.529	3.437	4.483
14	0.00060	0.00040	0.0005	17,400	11,600	14,500	6,259	4,173	5,216	10.903	7.269	9.068	6.276	4.184	5.230
16	0.00059	0.00041	0.0005	17,220	11,780	14,500	6,194	4,238	5,216	12.331	8.437	10.384	7.098	4.857	5.978
18	0.00059	0.00041	0.0005	17,080	11,920	14,500	6,143	4,289	5,216	13.759	9.605	11.682	7.920	5.529	6.725
20	0.00058	0.00042	0.0005	16,820	12,180	14,500	6,051	4,381	5,216	15.057	10.903	12.980	8.668	6.276	7.472
24	0.00057	0.00043	0.0005	16,550	12,450	14,500	5,955	4,477	5,216	17.783	13.369	15.576	10.236	7.696	8.966
28	0.00056	0.00044	0.0005	16,360	12,640	14,500	5,887	4,173	5,216	20.508	14.538	18.174	11.806	8.369	10.461
32	0.00056	0.00044	0.0005	16,220	12,780	14,500	5,835	4,597	5,216	23.234	18.302	20.768	13.375	10.536	11.955
36	0.00056	0.00044	0.0005	16,110	12,890	14,500	5,796	4,636	5,216	25.960	20.768	23.364	14.944	11.955	13.450
40	0.00055	0.00045	0.0005	16,020	12,980	14,500	5,764	4,668	5,216	28.686	23.234	25.960	16.513	13.375	14.944
48	0.00055	0.00045	0.0005	15,830	13,170	14,500	5,694	4,738	5,216	34.008	28.296	31.152	19.577	16.289	17.933
56	0.00054	0.00046	0.0005	15,690	13,310	14,500	5,644	4,788	5,216	39.329	33.359	36.344	22.640	19.203	20.922
64	0.00054	0.00046	0.0005	15,570	13,410	14,500	5,607	4,825	5,216	44.651	38.421	41.536	25.704	22.117	23.910
72	0.00053	0.00047	0.0005	15,500	13,490	14,500	5,578	4,854	5,216	49.973	43.483	46.728	28.767	25.031	26.899
80	0.00053	0.00047	0.0005	15,440	13,560	14,500	5,555	4,877	5,216	55.295	48.545	51.920	31.831	27.945	29.888
96	0.00053	0.00047	0.0005	15,320	13,680	14,500	5,509	4,923	5,216	65.809	58.799	62.304	37.883	33.848	35.866
112	0.00053	0.00047	0.0005	15,250	13,750	14,500	5,486	4,946	5,216	76.452	68.924	72.688	44.010	39.676	41.843
128	0.00052	0.00048	0.0005	15,180	13,820	14,500	5,461	4,972	5,216	86.966	79.178	83.072	50.062	45.579	47.821
	*			Stress = 29,000,000 A/d			Stress = 10,432,000 A/d			Force = 1,298 A			Force = 747.2 A		

A = allowance, d = mean size.

Values for stress and force are true only when hub diameter equals twice the hole diameter.

The force values are for fit 1 inch long. For other lengths multiply by the length of fit in inches.

* No values, due to smallest shaft member being smaller than the largest hole member.

The values of greatest hole stress are for mean diameter sizes only. For other sizes in a step, the interference per inch of diameter and hence the greatest hole stress will vary from the values given in the table by less than 10 per cent. Where greater accuracy for the intermediate steps is required, the interference per inch of diameter should be obtained by use of the formula: Average interference of metal = 0.0005 d, in which d is the diameter of the hole for which the size of the shaft is being computed.

TABLE 13.—HEAVY FORCE AND SHRINK FIT (CLASS 8)—CONSIDERABLE NEGATIVE ALLOWANCE SELECTIVE ASSEMBLY

These fits are used for steel holes where the metal can be stressed to its elastic limit. These fits cause excessive stress for cast-iron holes. Shrink fits are used where heavy force fits are impractical, as on locomotive wheel tires, heavy crank discs of large engines, etc.

(All Dimensions in Inches)

Size			Limits				Tightest Fit	Loosest Fit	Selected Fit
From	Up to and Inclusive	Mean	Hole or External Member		Shaft or Internal Member		Allowance	Allowance + tolerances	Average interference of metal
			+		+	+	−*	*	−*
0	3/16	1/8	0.0003	0.0000	0.0004	0.0001	0.0004	+0.0002	0.0001
3/16	5/16	1/4	0.0004	0.0000	0.0007	0.0003	0.0007	+0.0001	0.0003
5/16	7/16	3/8	0.0004	0.0000	0.0008	0.0004	0.0008	−0.0000	0.0004
7/16	9/16	1/2	0.0005	0.0000	0.0010	0.0005	0.0010	0.0000	0.0005
9/16	11/16	5/8	0.0005	0.0000	0.0011	0.0006	0.0011	−0.0001	0.0006
11/16	13/16	3/4	0.0005	0.0000	0.0013	0.0008	0.0013	−0.0003	0.0008
13/16	15/16	7/8	0.0006	0.0000	0.0015	0.0009	0.0015	−0.0003	0.0009
15/16	1 1/16	1	0.0006	0.0000	0.0016	0.0010	0.0016	−0.0004	0.0010
1 1/16	1 3/16	1 1/8	0.0006	0.0000	0.0017	0.0011	0.0017	−0.0005	0.0011
1 3/16	1 3/8	1 1/4	0.0006	0.0000	0.0019	0.0013	0.0019	−0.0007	0.0013
1 3/8	1 5/8	1 1/2	0.0007	0.0000	0.0022	0.0015	0.0022	−0.0008	0.0015
1 5/8	1 7/8	1 3/4	0.0007	0.0000	0.0025	0.0018	0.0025	−0.0011	0.0018
1 7/8	2 1/8	2	0.0008	0.0000	0.0028	0.0020	0.0028	−0.0012	0.0020
2 1/8	2 3/8	2 1/4	0.0008	0.0000	0.0031	0.0023	0.0031	−0.0015	0.0023
2 3/8	2 3/4	2 1/2	0.0008	0.0000	0.0033	0.0025	0.0033	−0.0017	0.0025
2 3/4	3 1/4	3	0.0009	0.0000	0.0039	0.0030	0.0039	−0.0021	0.0030
3 1/4	3 3/4	3 1/2	0.0009	0.0000	0.0044	0.0035	0.0044	−0.0026	0.0035
3 3/4	4 1/4	4	0.0010	0.0000	0.0050	0.0040	0.0050	−0.0030	0.0040
4 1/4	4 3/4	4 1/2	0.0010	0.0000	0.0055	0.0045	0.0055	−0.0035	0.0045
4 3/4	5 1/2	5	0.0010	0.0000	0.0060	0.0050	0.0060	−0.0040	0.0050
5 1/2	6 1/2	6	0.0011	0.0000	0.0071	0.0060	0.0071	−0.0049	0.0060
6 1/2	7 1/2	7	0.0011	0.0000	0.0081	0.0070	0.0081	−0.0059	0.0070
7 1/2	8 1/2	8	0.0012	0.0000	0.0092	0.0080	0.0092	−0.0068	0.0080
8 1/2	9 1/2	9	0.0012	0.0000	0.0102	0.0090	0.0102	−0.0078	0.0090
10 1/2	11 1/2	10	0.0013	0.0000	0.0113	0.0100	0.0113	−0.0087	0.0100
11 1/2	13	12	0.0014	0.0000	0.0134	0.0120	0.0134	−0.0106	0.0120
13	15	14	0.0014	0.0000	0.0154	0.0140	0.0154	−0.0126	0.0140
15	17	16	0.0015	0.0000	0.0175	0.0160	0.0175	−0.0145	0.0160
17	19	18	0.0016	0.0000	0.0196	0.0180	0.0196	−0.0164	0.0180
19	22	20	0.0016	0.0000	0.0216	0.0200	0.0216	−0.0184	0.0200
22	26	24	0.0017	0.0000	0.0257	0.0240	0.0257	−0.0223	0.0240
26	30	28	0.0018	0.0000	0.0298	0.0280	0.0298	−0.0262	0.0280
30	34	32	0.0019	0.0000	0.0339	0.0320	0.0339	−0.0301	0.0320
34	38	36	0.0020	0.0000	0.0380	0.0360	0.0380	−0.0340	0.0360
38	44	40	0.0021	0.0000	0.0421	0.0400	0.0421	−0.0379	0.0400
44	52	48	0.0022	0.0000	0.0502	0.0480	0.0502	−0.0458	0.0480
52	60	56	0.0023	0.0000	0.0583	0.0560	0.0583	−0.0537	0.0560
60	68	64	0.0024	0.0000	0.0664	0.0640	0.0664	−0.0616	0.0640
68	76	72	0.0025	0.0000	0.0745	0.0720	0.0745	−0.0695	0.0720
76	88	80	0.0026	0.0000	0.0826	0.0800	0.0826	−0.0774	0.0800
88	104	96	0.0027	0.0000	0.0987	0.0960	0.0987	−0.0933	0.0960
104	120	112	0.0029	0.0000	0.1149	0.1120	0.1149	−0.1091	0.1120
120	136	128	0.0030	0.0000	0.1310	0.1280	0.1310	−0.1250	0.1286

Explanatory Notes

In the table reproduced below many of the terms in common use in the shops of the country are given with the equivalent term which the A.S.M.E. Committee's report recommends:

Greatest tightness Least looseness Tighest fit Neutral zone Maximum metal	Are all common terms which have the same meaning as—	ALLOWANCE
Least tightness Greatest looseness Loosest fit Minimum metal	Are all common terms which have the same meaning as—	ALLOWANCE PLUS TOLERANCES
Difference between largest and smallest permissible size of either members. Variation in the size allowed	Now termed—	TOLERANCE

The basis for the foregoing recommended allowances and tolerances is a classification of fits quite commonly known to the manufacturing public. Interference between mating parts takes place at the exact basic value of the dimension; hence, an accepted pair of mating standard gages become the "go" gages for mating parts which will prevent interference at the basic value of the dimension.

Because of the lack of a uniform and acceptable method of measuring the fitting surfaces of the external members of a pair of mating parts, it is recommended that plugs, blocks, discs, and rods govern the checking of external members for the reason that usually the same measuring device will check for accuracy both the internal member and the gage for the external member, thus avoiding an interference when both members appear to have the same dimension.

TO ILLUSTRATE.—If a 2-inch hole be measured with an inside micrometer and a shaft be measured with an outside micrometer, and both measure exactly 2 inches, there is no assurance they will go together; but, unless there were a definite understanding in a contract, the pieces might be ruled acceptable by law. If, however, the 2-inch hole would receive a plug gage which measured exactly 2 inches by a measuring machine, it would also receive an accurately finished shaft of the same size when measured by the same machine.

It is well known that a correct pair of plug and ring gages 2 inches in diameter will each check parts that will go together. It is also well known that the character of fit depends on the rotundity, parallelism, size, and, in some cases, contour of the mating parts, and that for cylindrical fits in mating parts, plug and ring gages are

TABLE 14.—HEAVY FORCE AND SHRINK FIT (CLASS 8)—CONSIDERABLE NEGATIVE ALLOWANCE SELECTIVE ASSEMBLY

Mean Size	Interference of Metal per Inch of Mean Size, Inches			Greatest Hole Stress, Steel Shaft in Steel Hole, Pounds per Square Inch			Force for Pressing, Steel Shaft into Steel Hole, Tons		
	Tightest Fit	Loosest Fit	Selected Fit	Tightest Fit	Loosest Fit	Selected Fit	Tightest Fit	Loosest Fit	Selected Fit
1/8	0.00320	*	0.001	92,800	*	29,000	0.519	*	0.130
1/4	0.00280	*	0.001	81,200	*	29,000	0 909	*	0.389
3/8	0.00213	*	0.001	61,870	*	29,000	1.038	*	0.519
1/2	0 00200	*	0.001	58,000	*	29,000	1.298	*	0.649
5/8	0.00176	0.00016	0.001	51,040	4,640	29,000	1.428	0.130	0.779
3/4	0.00173	0.00040	0.001	42,270	11,600	29,000	1.687	0 389	1.038
7/8	0.00171	0.00034	0.001	49,710	9,943	29,000	1.947	0.389	1.168
1	0.00160	0.00040	0.001	46,400	11,600	29,000	2.077	0.519	1.298
1 1/8	0.00151	0.00044	0.001	43,840	12,890	29,000	2.207	0.649	1.428
1 1/4	0.00152	0.00056	0.001	44,080	16,230	29,000	2.466	0.909	1.687
1 1/2	0.00147	0.00053	0.001	42,530	15,470	29,000	2.856	1.038	1.947
1 3/4	0.00143	0.00062	0.001	41,430	18,230	29,000	3.245	1.428	2.336
2	0.00140	0.00060	0.001	40,600	17,400	29,000	3.634	1.558	2.596
2 1/4	0.00138	0.00066	0.001	39,960	17,910	29,000	4.024	1.947	2.985
2 1/2	0.00132	0.00068	0.001	38,280	19,720	29,000	4.283	2.207	3.245
3	0.00130	0.00070	0.001	37,700	20,300	29,000	5.062	2.726	3.894
3 1/2	0.00126	0.00074	0.001	36,460	21,540	29,000	5.711	3.375	4.543
4	0.00125	0.00075	0.001	36,250	21,750	29,000	6.490	3.894	5.192
4 1/2	0.00122	0.00078	0.001	35,440	22,560	29,000	7.139	4.543	5.841
5	0.00120	0.00080	0.001	34,800	23,200	29,000	7.788	5.192	6.490
6	0.00118	0.00082	0.001	34,317	23,680	29,000	9.216	6.360	7.788
7	0.00116	0.00084	0.001	33,570	24,440	29,000	10.514	7.658	9.086
8	0.00115	0 00085	0.001	33,350	24,650	29,000	11.942	8.826	10.384

9	0.00113	0.00087	0.001	32,870	25,130	29,000	13.240	10.124	11.682
10	0.00113	0.00087	0.001	32,770	25,233	29,000	14.667	11.293	12.980
12	0.00112	0.00088	0.001	32,390	25,610	29,000	17.393	13.759	15.576
14	0.00110	0.00090	0.001	31,900	26,100	29,000	19.989	16.355	18.172
16	0.00109	0.00091	0.001	31,720	26,290	29,000	22.715	18.821	20.768
18	0.00108	0.00091	0.001	31,580	26,420	29,000	25.441	21.287	23.364
20	0.00108	0.00092	0.001	31,370	26,680	29,000	28.037	23.883	25.960
24	0.00107	0.00093	0.001	31,050	26,940	29,000	33.359	28.945	31.152
28	0.00106	0.00094	0.001	30,860	27,130	29,000	38.680	34.008	36.344
32	0.00106	0.00094	0.001	30,710	27,280	29,000	44.002	39.070	41.536
36	0.00106	0.00094	0.001	30,600	27,390	29,000	49.324	44.132	46.728
40	0.00105	0.00095	0.001	30,510	27,480	29,000	54.646	49.194	51.020
48	0.00105	0.00095	0.001	30,330	27,680	29,000	65.160	59.448	62.304
56	0.00104	0.00096	0.001	30,190	27,810	29,000	75.673	69.703	72.688
64	0.00104	0.00096	0.001	30,080	27,900	29,000	86.187	79.957	83.072
72	0.00103	0.00097	0.001	30,000	27,990	29,000	96.701	90.211	93.456
80	0.00103	0.00097	0.001	29,940	28,060	29,000	107.113	100.465	103.840
96	0.00103	0.00097	0.001	29,810	28,180	29,000	128.115	121.103	124.608
112	0.00103	0.00097	0.001	29,750	28,250	29,000	149.140	141.612	145.376
128	0.00102	0.00098	0.001	29,690	28,320	29,000	170.038	162.250	166.144
				Stress = 29,000,000 A/d			Force = 1,298 A		

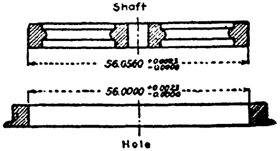
A = allowance, d = mean size.

Values for stress and force are true only when hub diameter equals twice the hole diameter.

The force values are for a fit 1 inch long. For other lengths multiply by the length of fit in inches.

* No values, due to smallest shaft member being smaller than the largest hole member.

The values of greatest hole stress are for mean diameter sizes only. For other sizes in a step, the interference per inch of diameter and hence the greatest hole stress will vary from the values given in the table by less than 10 per cent. Where greater accuracy for the intermediate steps is required, the interference per inch of diameter should be obtained by use of the formula: Average interference of metal = 0.001d, in which d is the diameter of the hole for which the size of the shaft is being computed.



FORMULAS FOR RECOMMENDED ALLOWANCES AND TOLERANCES

Class of Fit	Method of Assembly	Allowance	Selected Average Interference of Metal	Hole Tolerance	Shaft Tolerance
1. Loose	Strictly interchangeable	$0.0025\sqrt[3]{d^2}$		$0.0025\sqrt[3]{d}$	$0.0025\sqrt[3]{d}$
2. Free	Strictly interchangeable	$0.0014\sqrt[3]{d^2}$		$0.0013\sqrt[3]{d}$	$0.0013\sqrt[3]{d}$
3. Medium	Strictly interchangeable	$0.0009\sqrt[3]{d^2}$		$0.0008\sqrt[3]{d}$	$0.0008\sqrt[3]{d}$
4. Snug	Strictly interchangeable	0.0000		$0.0006\sqrt[3]{d}$	$0.0004\sqrt[3]{d}$
5. Wringing	Selective assembly		0.0000	$0.0006\sqrt[3]{d}$	$0.0004\sqrt[3]{d}$
6. Tight	Selective assembly		$0.00025d$	$0.0006\sqrt[3]{d}$	$0.0006\sqrt[3]{d}$
7. Medium force	Selective assembly		$0.0005d$	$0.0006\sqrt[3]{d}$	$0.0006\sqrt[3]{d}$
8. Heavy force or shrink	Selective assembly		$0.001d$	$0.0006\sqrt[3]{d}$	$0.0006\sqrt[3]{d}$
9. Reciprocating	Interchangeable	0.0000		$0.0008\sqrt[3]{d}$	$0.0008\sqrt[3]{d}$

d = diameter of fit in inches.
The formulas for allowance values give the ideal condition of fit for Classes 1 to 4.
The formulas for selected average interference of metal give the ideal condition of fit for Classes 5 to 8.

the only sure means of determining whether or not parts will go together. If either member of a pair of mating parts is three- or five-cornered, a snap gage or micrometer will not ensure their going together.

In the foregoing allowances and tolerances, the best practice available was considered, and where differences occurred, a compromise was attempted. The tolerances on holes apply only to reamed holes, or holes having a finish equivalent to reaming. From the standpoint of satisfactory performance, the tightest and loosest fits permissible are the all-important considerations. From a manufacturing standpoint, tolerances are the important factors. Hence both the tightest and loosest fits permissible must combine the tolerance and allowance, and therefore both allowance and tolerance must be considered for all-round satisfactory conditions.

It is not deemed to be feasible to include in this report allowances and tolerances which will apply to all work. In the industries many so-called standard fits are made which are not interchangeable, and an attempt to make them so would be prohibitive in cost. These fits, however, must be made on a production basis, and it is believed that the tables here given will be found to contain allowances and tolerances which are suitable for most work, even if some selection or individual fitting of parts is desired.

In choosing the class of fit for manufacture, the engineer should keep in mind that cost usually increases proportionately to the accuracy required, and no finer class of fit should be chosen than the functional requirements actually demand. It is axiomatic that the closer the fit, the smaller the manufacturing tolerance, and, usually, the greater the cost. The length of engagement of the fit also plays an important part in the selection of the class of fit for a piece of work. It is obvious that a long engagement will tolerate more looseness than a short one, and due regard should be paid to this feature.

INTERNATIONAL STANDARDS

Revision of the American tentative standard for allowances and tolerances for cylindrical parts and limit gages (B4a–1925) has been under consideration for several years. Meanwhile, the so-called "ISA System of Fits" has been developed by a technical committee of the International Standards Association, a federation of the national standardizing bodies in 21 countries, including the American Standards Association. The ISA System of Fits, established to create international uniformity of practice, has already been adopted in 15 countries as their national standard. The ASA committee is studying the question whether the ISA system can be adopted, either in its original or a somewhat modified form, as an American standard. The British Standards Institution is making a similar study.

A.S.M.E. SPECIFICATIONS FOR PLAIN LIMIT GAGES

The following specifications are for the purpose of establishing definite limits for plain limit gages rather than for the purpose of specifying the gages required for the various inspection operations.

Gages are classified according to accuracy into Classes X, Y, and Z, the Class X being the closest to the extreme limits. The tolerance limits on Classes Y and Z "go" gages are placed inside the extreme product limits to provide allowance for wear of the gages. The tolerances on all "not go" gages, however, are applied from the extreme product limit as the starting point, as no allowance for wear is necessary. The selection of gages from among these classes for use in the inspection of product depends entirely upon the specifications for the product. For example, Table 6, page 741, in the production of parts to Class 3, Medium Fit Specifications, Class X gages may be required for all purposes. For parts made to Class 1, Loose Fit Specifications, Class Z gages may be satisfactory for all purposes.

Gages should be tested periodically for wear and to ensure that they are properly distributed. When successive inspections in the same plant are involved, it is good practice to inspect all gages of the same nominal size against each other periodically and to distribute these gages so that the earlier inspections are made of those which are the greatest amount inside the component limits; the later inspections will be made of those which are closest in size to the component limits. "Go" gages may be permitted to wear to the extreme product limits. It is purely a question of economy as to when the "not go" gage should be discarded. Continued use reduces the available working tolerance on the product, and the resulting loss must be balanced against the cost of a new gage.

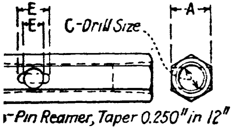
Plain plug gages of 1½ inches, and less, diameter should be made with plug inserted in the handle and securely fastened. Plain plug gages of more than 1½ inches diameter should have the gaging blank so made as to be reversible. The "not go" plain plug gage should be distinguished from the "go" gage by having it noticeably shorter.

Ring gages—both "go" and "not go"—should, if made circular, have their outside diameters knurled. The "not go" ring should be distinguished from the "go" ring by being noticeably thinner.

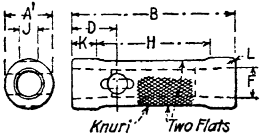
Snap gages may be either adjustable or nonadjustable. It is recommended that all snap gages up to and including ⅛ inch be of the built-up type. Sufficient clearance in the depth of the gage should be provided to permit the gaging of cylindrical work.

Snap gages for measuring lengths and diameters may have one gaging dimension only, or may have a maximum and minimum gaging dimension both on one end or on opposite ends of the gage. When the maximum and minimum gaging dimensions are placed on opposite ends of the gage, the maximum or "go" end of the snap gage should be distinguished from the minimum or "not go" and by having the corners of the gage on the "go" end noticeably chamfered.

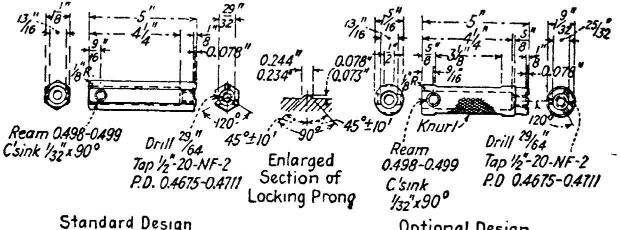
Dimensions recommended for plain plug, ring, and snap gages are given in tables that follow.



Standard Design



Optional Design



Standard Design

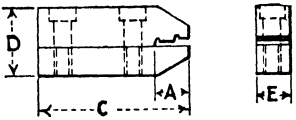
Optional Design

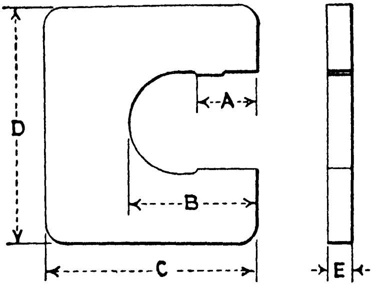
No. 6 Handle. Range: Above 1.510 to and including 2.510 inches

Plain Cylindrical Plug Gage Handles Taper Lock Design, Range Above 0.240 to and including 1.510 Inches

Size	Range, Plain Plug Diameters		General Dimensions												
	Above	To and Including	*A*	*A'*	*B*	*C* Drill Size	*D*	*E*	F Minimum	F Maximum	*G*	*H*	*J*	*K*	*L*
	Inches						Inches				No.	Inches			
1	0.240	0.365	3/8	7/16	2 3/4	7/32	25/32	1/8 by 1/2 Diameter	0.239	0.240	4	1 3/4	7/32	1/2	1/16
2	0.365	0.510	1/2	5/8	3	L (0.290)	25/32	15/64	0.309	0.310	6	2	3/8	1/2	1/16
3	0.510	0.825	11/16	13/16	3 1/4	25/64	27/32	11/32	0.409	0.410	7	2 1/4	7/16	1/2	3/32
4	0.825	1.135	7/8	1 1/16	3 5/8	37/64	63/64	3/8	0.609	0.610	10	2 1/2	7/16	9/16	3/32
5	1.135	1.510	1 1/8	1 5/16	4	25/32	1 1/8	7/16	0.809	0.810	11	2 3/4	1/2	5/8	1/8
5 (optional, see note)	1.510	2.510	1 1/8	1 5/16	4	25/32	1 1/8	7/16	0.809	0.810	11	2 3/4	1/2	5/8	1/8

NOTE: The use of taper lock plain cylindrical plug gaging members and handles is optional in the range above 1.510 to and including 2.510 inches, but the use of the reversible design is standard for all sizes above 1.510 inches.





Snap Gages for Diameters

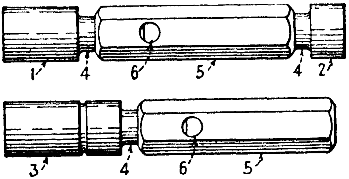
Where standard adjustable gages cannot conveniently be used
(Dimensions in Inches)

Nominal Size	*A*	*C*	*D*	*E*
Up to $\frac{1}{8}$	$\frac{3}{8}$	$1\frac{5}{8}$	$\frac{11}{16}$	$\frac{7}{16}$

Nominal Size		*A*	*B*	*C*	*D*	*E*
Over	To					
$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{5}{8}$	$1\frac{5}{8}$	1	$\frac{1}{8}$
$\frac{1}{4}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{5}{8}$	$1\frac{5}{8}$	$1\frac{1}{4}$	$\frac{1}{8}$
$\frac{3}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	1	2	$1\frac{1}{2}$	$\frac{3}{16}$
$\frac{5}{8}$	$\frac{7}{8}$	$\frac{5}{8}$	$1\frac{1}{8}$	2	2	$\frac{3}{16}$
$\frac{7}{8}$	$1\frac{1}{8}$	$\frac{5}{8}$	$1\frac{3}{8}$	$2\frac{1}{4}$	$2\frac{1}{2}$	$\frac{1}{4}$
$1\frac{1}{8}$	$1\frac{3}{8}$	$\frac{5}{8}$	$1\frac{3}{8}$	$2\frac{1}{4}$	3	$\frac{1}{4}$
$1\frac{3}{8}$	$1\frac{5}{8}$	$\frac{3}{4}$	$1\frac{5}{8}$	$2\frac{3}{4}$	$3\frac{1}{2}$	$\frac{1}{4}$
$1\frac{5}{8}$	2	$\frac{3}{4}$	$1\frac{7}{8}$	$3\frac{1}{8}$	4	$\frac{1}{4}$
2	$2\frac{1}{4}$	$\frac{3}{4}$	2	$3\frac{1}{4}$	$4\frac{1}{2}$	$\frac{1}{4}$
$2\frac{1}{4}$	$2\frac{1}{2}$	$\frac{3}{4}$	$2\frac{1}{8}$	$3\frac{3}{8}$	$4\frac{3}{4}$	$\frac{1}{4}$
$2\frac{1}{2}$	$2\frac{3}{4}$	$\frac{3}{4}$	$2\frac{1}{4}$	$3\frac{1}{2}$	5	$\frac{1}{4}$
$2\frac{3}{4}$	3	$\frac{3}{4}$	$2\frac{3}{8}$	$3\frac{5}{8}$	$5\frac{1}{4}$	$\frac{1}{4}$

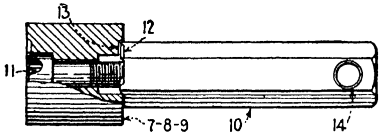
STANDARD GAGES

The American Gage Design Committee's recommendations for gage standards have been accepted as of Jan. 1, 1931 and are outlined herewith. The two types of plug gages are shown in Figs. 20 and 21. The first holds the gaging plug in the handle by a taper of $\frac{1}{4}$ inch per foot and is recommended from 0.059 to 1.510 inches but is optional up to 2.510 inches. For larger sizes, the type shown in Fig. 21 is advised. Three prongs on the handle, 120 degrees apart, mate with corresponding grooves on the ends of the plugs and

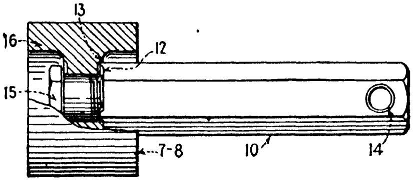


Range: Above 0.059 to and including 0.510 inches; Optional above 1.510 to and including 2.510 inches

FIG. 20



Range: Above 1.510 to and including 2.510 inches



Range. Above 2.510 to and including 4.510 inches

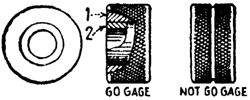
FIG. 21

FIGS. 20 and 21.—American Gage Design Standard Plain Cylindrical Plug Gages, Details of Construction

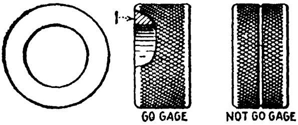
1. "Go" Gaging member.
2. "Not go" gaging member.
3. Progressive gaging member.
4. Shank.
5. Taper lock handle.
6. Drift hole (or slot).
7. "Go" gaging member.
8. "Not go" gaging member.
9. Progressive gaging member.
10. Handle for reversible gage.
11. Socket head screw.
12. Locking prong.
13. Locking groove.
14. Cross-pin hole.
15. Hexagon head screw.
16. Web.

prevent turning. Details of both types of handles are shown. Thread plug gages are made in the same way. Only one drift hole is made in the taper handle, the other plug being driven out through a hole in the handle itself. Dimensions are given only for medium sizes. Complete dimensions are given in the Committee's report.

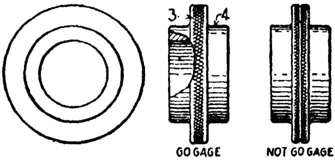
Ring gages are shown in Fig. 22. On small sizes it is advised that a hardened-steel bushing be used in a soft-steel ring, as shown. Large gages have a flange for easy handling. "Not go" gages have a ring turned around the body.



Range: Above 0.059 to and including 0.510 inch



Range: Above 0.510 to and including 1.510 inches



Range: Above 1.510 to and including 4.510 inches

1. Body 3. Flange
2. Bushing 4. Hub

FIG. 22.—American Gage Design Standard Plain Ring Gages, Details of Construction

Wear and Tolerance of Gages[1]

Gaging work is complicated by the fact that the gage maker must be allowed a tolerance and that gages wear in use. Many disputes between production and inspection are due to worn gages, in either or both departments. All gages should be inspected frequently; in some cases every hour, in others, every day or week. It is customary in most shops to give the worn gages to production so that, if the work does not pass the inspectors' gages it can be salvaged. Others feel that inspection gages should have somewhat wider tolerances than those used by production.

Gages should be uniformly hard although extreme hardness is not essential. For this reason high-carbon alloy steels are considered best for gages. Soft steel with a thin casehardening is apt to become bruised. In gaging extremely hard work, a file-soft gage is said to give longer life than a hard gage. It is more important to have gaging surfaces very smooth than extremely hard.

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[1] E. J. Bryant—Greenfield Tap & Die Corp.

Plug gages wear faster at the front end, and this must be considered in setting wear limits. A gage should usually be discarded when it is 0.0002 inch small, ¼ inch from the end, and 0.0001 inch small at the back end. Dirty work or work that has grit in the holes, as in grinding, wears gages rapidly. The use of dogs or clamps on gages increases the wear. Aluminum, brass, and cast iron wear gages much faster than soft steel. It is sometimes advisable to use a small amount of light lubricant when gaging dry brass or aluminum. Gages should be kept clean at all times.

A general average for gage wear is 0.0001 inch per 1,000 gagings, when the gages are hard and lapped smooth.

Gage makers' tolerances allowed by the Greenfield Tap & Die Corp. are as follows:

TABLE 15.—GAGE MAKERS' TOLERANCES* FOR CYLINDRICAL PLUG GAGES

Class	Size Range	Tolerance
X—Precision lapped, for master and reference gages	0.060–0.825	0.00004
	0.826–1.510	0.00006
	1.511–2.510	0.00008
	2.511–4.510	0.00010
Y—Lapped finish, for inspection and working gages	0.060–0.825	0.00008
	0.826–1.510	0.00010
	1.511–2.510	0.00014
	2.511–4.510	0.00018
Z—Ground finish, for wide manufacturing limits	0.060–0.825	0.00010
	0.826–1.510	0.00012
	1.511–2.510	0.00018
	2.511–4.510	0.00025

* Tolerances are applied from basic plus for "go" and master gages and half the tolerance plus and half minus for "not go" gages.

Allowances for Wear

"Go" plug gages may be made larger than the minimum hole size, usually by the amount that represents the production tolerance for the gage, and in some instances a definite wear allowance is made in addition to the necessary production tolerance. Tolerances in one plant are shown in Table 15, which gives the regular gage maker's tolerances used for plain plug gages, and in Table 16, which gives the ordinary gage maker's production tolerances and allowances for thread gages.

The wear on "not go" gages is considerably less severe than on "go" gages. Generally three "go" gages will be used to one "not go" gage. No allowances for wear other than the gage maker's tolerance is provided on any "not go" gages. There are three practices regarding the applications of tolerances to the "not go" gage, as follows:

1. The tolerance is divided between plus and minus.
2. Minus tolerance only is allowed on plug gages.
3. Plus tolerance only is allowed on plug gages.

Some manufacturers split the gage maker's tolerance on the "not go" gage. For instance, where the gage maker's tolerance is 0.0002 inch, the "not go" gage would be basic size plus or minus 0.0001 inch.

The National Screw Thread Commission's Report makes the gage maker's tolerance minus on "not go" plug gages.

The General Motors standard specification for pitch diameter on "not go" screw-thread gages is the maximum hole size plus gage

TABLE 16.—TOLERANCES FOR ALL "GO" AND "NOT GO" THREAD GAGES

Threads per Inch	Pitch Diameter, in Inches*			Lead, in Inches ±†	Half-Angle of Thread, Minutes ±	Major and Minor Diameter, in Inches
	Class X from 0 to	Class XX				
		From	To			
80	0.0002	0.0001	0.0003	0.0002	30	0.0003
72	0.0002	0.0001	0.0003	0.0002	30	0.0003
64	0.0002	0.0001	0.0003	0.0002	30	0.0004
56	0.0002	0.0001	0.0003	0.0002	30	0.0004
48	0.0002	0.0001	0.0003	0.0002	30	0.0004
44	0.0002	0.0001	0.0003	0.0002	20	0.0004
40	0.0002	0.0001	0.0003	0.0002	20	0.0004
36	0.0002	0.0001	0.0003	0.0002	20	0.0004
32	0.0002	0.0001	0.0003	0.0003	15	0.0004
28	0.0002	0.0001	0.0003	0.0003	15	0.0005
24	0.0002	0.0001	0.0003	0.0003	15	0.0005
20	0.0003	0.00015	0.00045	0.0003	15	0.0005
18	0.0003	0.00015	0.00045	0.0003	10	0.0005
16	0.0003	0.00015	0.00045	0.0003	10	0.0006
14	0.0003	0.00015	0.00045	0.0003	10	0.0006
13	0.0003	0.00015	0.00045	0.0003	10	0.0006
12	0.0003	0.00015	0.00045	0.0003	10	0.0006
11	0.0003	0.00015	0.00045	0.0003	10	0.0006
10	0.0003	0.00015	0.00045	0.0003	10	0.0006
9	0.0003	0.00015	0.00045	0.0003	10	0.0007
8	0.0004	0.0002	0.0006	0.0004	5	0.0007
7	0.0004	0.0002	0.0006	0.0004	5	0.0007
6	0.0004	0.0002	0.0006	0.0004	5	0.0008
5	0.0004	0.0002	0.0006	0.0004	5	0.0008
4½	0.0004	0.0002	0.0006	0.0004	5	0.0008
4	0.0004	0.0002	0.0006	0.0004	5	0.0009
3½	0.0004	0.0002	0.0006	0.0004	5	0.0009

* On "go" plugs, the tolerance is plus; on "go" rings, minus; on "not go" plugs, minus; and on "not go" rings, plus.

† Allowable variation in lead between any two threads not farther apart than the started length of engagement, which is equal to the basic major diameter.

maker's tolerance applied as follows: plus 0.0002 inch on sizes $\frac{1}{4}$ to $\frac{9}{16}$ inch, inclusive, and maximum hole size to 0.0003 inch plus on sizes $\frac{5}{8}$ to $1\frac{1}{2}$ inches. The corresponding "go" tolerances are from basic size to plus 0.0002 inch on sizes $\frac{1}{4}$ to $\frac{9}{16}$ inch, and basic to plus 0.0003 inch on sizes $\frac{5}{8}$ to $1\frac{1}{2}$ inches.

It will be seen that by following the first and last practices we are liable to have gages that measure outside the production tolerance. However, with the general ruling that the "not go" cylindrical gage must not pass through the hole being gaged and a ruling of a Government inspection department that a "not go" thread gage must not enter more than two turns, it is easily demonstrated that a gage 0.0001 inch or even less under the nominal size will easily pass through a hole that is to size. This means that good work will be rejected if the gage manufacturing tolerance is minus and the "not go" gage is undersize.

As a matter of fact, under most working conditions it is possible to pass a gage through a hole that is 0.0001 inch smaller than the gage by using pressure, but this is not recommended. This condition should be taken into consideration if we are to rule that work is acceptable only when the "not go" gage does not enter, and it seems that the "not go" gage should be permitted to have a plus tolerance.

From the foregoing it is evident that the product will be little if any over the production limits if either the first or last of these practices is followed. As the wear tends to reduce the size within the production limits, it seems that the General Motors application on thread gages is the more economical and would lead to no difficulty on properly designed parts.

It must be remembered that using a minus gage-production tolerance on "not go" plug gages greatly reduces the working tolerance in producing the parts, particularly where these tolerances are between 0.0005 and 0.002 inch. The general working tolerances for various classes of interchangeable cylindrical fits, as given in the American Standard[1] are shown in Table 17, and the National Screw Thread Commission's Class-2 and Class-3 pitch-diameter tolerances for thread-gage work are shown in Table 18.

Applying the "not go" gage tolerance on the minus side may reduce the production tolerance by 20 per cent or more. There is no danger in making the "not go" gage tolerance plus or minus one-half the gage maker's tolerance as the permissible error would be much greater than the gage tolerance, in nearly all cases.

There is an old fallacy that a 1-inch plug gage will not enter a 1-inch ring gage. In reality, the plug may be 0.0001 inch larger than the hole and be forced in by hand with a a little lubricant, but it is not good practice. Even with gages men have different ideas as to how easily they should go in, or on. Some use force and spring the gage or the work, others let them drop over by their own weight. Accurate measuring devices will show how much these two methods vary in actual sizes.

In many cases worn gages will return to size if laid away for a year or two. Some people plate worn gages with chromium to restore size and give a hard surface; and although some find this successful,

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[1] See American Engineering Standards Committee Report B4a—1925, Tolerances, Allowances and Gages for Metal Fits.

TABLE 17.—ALLOWANCES AND TOLERANCES FOR INTERCHANGEABLE METAL FITS

Size			Class 1 Limits				Class 2 Limits				Class 3 Limits				Class 4 Limits			
From	Up to and Including	Mean	Hole or External Member		Shaft or Internal Member		Hole or External Member		Shaft or Internal Member		Hole or External Member		Shaft or Internal Member		Hole or External Member		Shaft or Internal Member	
			+		−	−	+		−	−	+		−	−	+			−
0	3/16	1/8	0.001	0.000	0.001	0.002	0.0007	0.0000	0.0004	0.0011	0.0004	0.0000	0.0002	0.0006	0.0003	0.0000	0.0000	0.0002
3/16	5/16	1/4	0.002	0.000	0.001	0.003	0.0008	0.0000	0.0006	0.0014	0.0005	0.0000	0.0004	0.0009	0.0004	0.0000	0.0000	0.0003
5/16	7/16	3/8	0.002	0.000	0.001	0.003	0.0009	0.0000	0.0007	0.0016	0.0006	0.0000	0.0005	0.0011	0.0004	0.0000	0.0000	0.0003
7/16	9/16	1/2	0.002	0.000	0.002	0.004	0.0010	0.0000	0.0009	0.0019	0.0006	0.0000	0.0006	0.0012	0.0005	0.0000	0.0000	0.0003
9/16	11/16	5/8	0.002	0.000	0.002	0.004	0.0011	0.0000	0.0010	0.0021	0.0007	0.0000	0.0007	0.0014	0.0005	0.0000	0.0000	0.0003
11/16	13/16	3/4	0.002	0.000	0.002	0.004	0.0012	0.0000	0.0012	0.0024	0.0007	0.0000	0.0007	0.0014	0.0005	0.0000	0.0000	0.0004
13/16	15/16	7/8	0.002	0.000	0.002	0.004	0.0012	0.0000	0.0013	0.0025	0.0008	0.0000	0.0008	0.0016	0.0006	0.0000	0.0000	0.0004
15/16	1 1/16	1	0.003	0.000	0.003	0.006	0.0013	0.0000	0.0014	0.0027	0.0008	0.0000	0.0009	0.0017	0.0006	0.0000	0.0000	0.0004
1 1/16	1 3/16	1 1/8	0.003	0.000	0.003	0.006	0.0014	0.0000	0.0015	0.0029	0.0008	0.0000	0.0010	0.0018	0.0006	0.0000	0.0000	0.0004
1 3/16	1 3/8	1 1/4	0.003	0.000	0.003	0.006	0.0014	0.0000	0.0016	0.0030	0.0009	0.0000	0.0010	0.0019	0.0006	0.0000	0.0000	0.0004
1 3/8	1 5/8	1 1/2	0.003	0.000	0.003	0.006	0.0015	0.0000	0.0018	0.0033	0.0009	0.0000	0.0012	0.0021	0.0007	0.0000	0.0000	0.0005
1 5/8	1 7/8	1 3/4	0.003	0.000	0.004	0.007	0.0016	0.0000	0.0020	0.0036	0.0010	0.0000	0.0013	0.0023	0.0007	0.0000	0.0000	0.0005
1 7/8	2 1/8	2	0.003	0.000	0.004	0.007	0.0016	0.0000	0.0022	0.0038	0.0010	0.0000	0.0014	0.0024	0.0008	0.0000	0.0000	0.0005
2 1/8	2 3/8	2 1/4	0.003	0.000	0.004	0.007	0.0017	0.0000	0.0024	0.0041	0.0010	0.0000	0.0015	0.0025	0.0008	0.0000	0.0000	0.0005
2 3/8	2 3/4	2 1/2	0.003	0.000	0.005	0.008	0.0018	0.0000	0.0026	0.0044	0.0011	0.0000	0.0017	0.0028	0.0008	0.0000	0.0000	0.0005
2 3/4	3 1/4	3	0.004	0.000	0.005	0.009	0.0019	0.0000	0.0029	0.0048	0.0012	0.0000	0.0019	0.0031	0.0009	0.0000	0.0000	0.0006
3 1/4	3 3/4	3 1/2	0.004	0.000	0.006	0.010	0.0020	0.0000	0.0032	0.0052	0.0012	0.0000	0.0021	0.0033	0.0009	0.0000	0.0000	0.0006
3 3/4	4 1/4	4	0.004	0.000	0.006	0.010	0.0020	0.0000	0.0035	0.0056	0.0013	0.0000	0.0023	0.0036	0.0010	0.0000	0.0000	0.0006
4 1/4	4 3/4	4 1/2	0.004	0.000	0.007	0.011	0.0021	0.0000	0.0038	0.0059	0.0013	0.0000	0.0025	0.0038	0.0010	0.0000	0.0000	0.0007
4 3/4	5 1/2	5	0.004	0.000	0.007	0.011	0.0022	0.0000	0.0041	0.0063	0.0014	0.0000	0.0026	0.0040	0.0010	0.0000	0.0000	0.0007
5 1/2	6 1/2	6	0.005	0.000	0.008	0.013	0.0024	0.0000	0.0046	0.0070	0.0015	0.0000	0.0030	0.0045	0.0011	0.0000	0.0000	0.0007
6 1/2	7 1/2	7	0.005	0.000	0.009	0.014	0.0025	0.0000	0.0051	0.0076	0.0015	0.0000	0.0033	0.0048	0.0011	0.0000	0.0000	0.0008
7 1/2	8 1/2	8	0.005	0.000	0.010	0.015	0.0026	0.0000	0.0056	0.0082	0.0016	0.0000	0.0036	0.0052	0.0012	0.0000	0.0000	0.0008

Class 1—Loose Fit, Large Allowance.—Provides for considerable freedom; embraces certain fits where accuracy is not essential. *Class 2—Free Fit, Liberal Allowance.*—For running fits with speeds of 600 revolutions per minute or over, and journal pressures of 600 pounds per square inch or over. *Class 3—Medium Fit, Medium Allowance.*—For running fits under 600 revolutions per minute and with journal pressures less than 600 pounds per square inch; also for sliding fits, and the more accurate machine-tool and automotive parts. *Class 4—Snug Fit, Zero Allowance.*—This is the closest fit which can be assembled by hand and necessitates work of considerable precision. It should be used where no perceptible shake is permissible and where moving parts are not intended to move freely under load.

Table 18.—National Screw Thread Commission's Product Limits and Inspection-Gage Tolerances on Pitch Diameter

Pitch	Class 2,* Product	Class 3,* Product	Class X,† Gage
80	0.0017	0.0013	0.0002
72	0.0018	0.0013	0.0002
64	0.0019	0.0014	0.0002
56	0.0020	0.0015	0.0002
48	0.0022	0.0016	0.0002
44	0.0023	0.0016	0.0002
40	0.0024	0.0017	0.0002
36	0.0025	0.0018	0.0002
32	0.0027	0.0019	0.0002
28	0.0031	0.0022	0.0002
24	0.0033	0.0024	0.0002
20	0.0036	0.0026	0.0003
18	0.0041	0.0030	0.0003
16	0.0045	0.0032	0.0003
14	0.0049	0.0036	0.0003
13	0.0052	0.0037	0.0003
12	0.0056	0.0040	0.0003
11	0.0059	0.0042	0.0003
10	0.0064	0.0045	0.0003
9	0.0070	0.0049	0.0003
8	0.0076	0.0054	0.0004
7	0.0085	0.0059	0.0004
6	0.0101	0.0071	0.0004
5	0.0116	0.0082	0.0004
4½	0.0127	0.0089	0.0004
4	0.0140	0.0097	0.0004

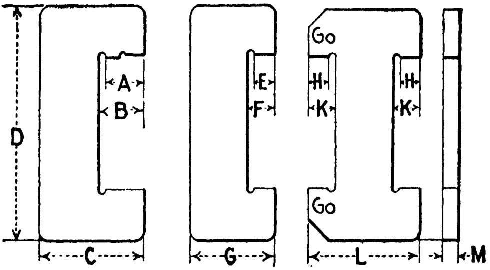
* On products, the maximum hole is basic size plus the amount given for tolerance on the pitch diameter and the minimum screw is basic minus the amount given for tolerance on the pitch diameter. The basic size is minimum for the hole and maximum for the screw.

† On "go" plug gages, the tolerance is plus; on "go" ring gages minus; on "not go" plug gages, minus; and on "not go" rings, plus. Check gages or setting plugs for ring gages take the same tolerance as the ring.

others complain that the plating flakes off, evidently the result of improper plating methods.

Tungsten carbide is used in some gages where they are used in mass production so that the cost is justified. Others use diamond contact points in special gages. For most work a good alloy steel, uniformly hardened and lapped very smooth after grinding, gives satisfactory results.

Many gage makers and users feel that smoothness is more important than hardness to insure long gage life. Modern grinding practices permit much smoother surfaces than were formerly thought possible. Finishes of from 1½ to 4 micro-inches (millionths of an inch) are now being produced commercially on Blanchard and other surface grinding machines.



SNAP GAGES FOR LENGTHS

Where standard adjustable gages cannot conveniently be used
(Dimensions in Inches)

Nominal Size		A	B	C	D	E	F	G	H	K	L	Thickness
Over	To											M
1/8	1/4	3/8	1/2	1 5/8	1	3/16	5/16	1 1/8	3/16	5/16	1 1/2	1/8
1/4	3/8	3/8	1/2	1 5/8	1 1/4	3/16	5/16	1 1/8	3/16	5/16	1 1/2	1/8
3/8	5/8	5/8	3/4	1 5/8	1 1/2	5/16	7/16	1 1/4	5/16	7/16	1 3/4	3/16
5/8	7/8	5/8	3/4	1 5/8	2	5/16	7/16	1 1/4	5/16	7/16	1 3/4	3/16
7/8	1 1/8	5/8	3/4	1 5/8	2 1/2	5/16	7/16	1 1/4	5/16	7/16	1 3/4	1/4
1 1/8	1 3/8	5/8	3/4	1 5/8	2 3/4	5/16	7/16	1 1/4	5/16	7/16	1 3/4	1/4
1 3/8	1 5/8	5/8	3/4	1 5/8	3	5/16	7/16	1 1/4	5/16	7/16	1 3/4	1/4
1 5/8	2	5/8	3/4	1 5/8	3 1/2	5/16	7/16	1 1/4	5/16	7/16	1 3/4	1/4
2	2 1/4	5/8	3/4	1 5/8	3 3/4	5/16	7/16	1 1/4	5/16	7/16	1 2/4	1/4
2 1/4	2 1/2	5/8	3/4	1 5/8	4	5/16	7/16	1 1/4	5/16	7/16	1 3/4	1/4
2 1/2	2 3/4	5/8	3/4	1 5/8	4 1/4	5/16	7/16	1 1/4	5/16	7/16	1 3/4	1/4
2 3/4	3	5/8	3/4	1 5/8	4 1/2	5/16	7/16	1 1/4	5/16	7/16	1 3/4	1/4
	3 1/4	5/8	3/4	1 3/4	4 3/4	5/16	7/16	1 3/8	5/16	7/16	1 7/8	1/4
3 1/4	3 1/2	5/8	3/4	1 3/4	5	5/16	7/16	1 3/8	5/16	7/16	1 7/8	1/4
3 1/2	3 3/4	5/8	3/4	1 3/4	5 1/4	5/16	7/16	1 3/8	5/16	7/16	1 7/8	1/4
3 3/4	4	5/8	3/4	1 3/4	5 1/2	5/16	7/16	1 3/8	5/16	7/16	1 7/8	1/4
4	4 1/4	5/8	3/4	2	5 3/4	5/16	7/16	1 5/8	5/16	7/16	2 1/8	1/4
4 1/4	4 1/2	5/8	3/4	2	6	5/16	7/16	1 5/8	5/16	7/16	2 1/8	1/4
4 1/2	4 3/4	5/8	3/4	2	6 1/4	5/16	7/16	1 5/8	5/16	7/16	2 1/8	1/4
4 3/4	5	5/8	3/4	2	6 1/2	5/16	7/16	1 5/8	5/16	7/16	2 1/8	1/4
5	5 1/4	5/8	3/4	2 1/4	6 3/4	5/16	7/16	1 7/8	5/16	7/16	2 3/8	1/4
5 1/4	5 1/2	5/8	3/4	2 1/4	7	5/16	7/16	1 7/8	5/16	7/16	2 3/8	1/4
5 1/2	5 3/4	5/8	3/4	2 1/4	7 1/4	5/16	7/16	1 7/8	5/16	7/16	2 3/8	1/4
5 3/4	6	5/8	3/4	2 1/4	7 1/2	5/16	7/16	1 7/8	5/16	7/16	2 3/8	1/4

TOLERANCES FOR PLAIN PLUG, RING, AND SNAP GAGES

Size of gage, inches	Tolerances for "go" gages				Class Z		Tolerances for "not go" gages	
	Class X		Class Y					
	Limits, inch	Tol., inch	Limits, inch	Tol., inch	Limits, inch	Tol., inch	Limits, inch	Tol., inch
0–2 incl.	0.0000	0.0001	0.0001	0.0001	0.0002	0.0001	0.0000	0.0001
	0.0001	......	0.0002	......	0.0003	......	0.0001	......
2–4	0.0000	0.0002	0.0001	0.0002	0.0003	0.0002	0.0000	0.0002
	0.0002	......	0.0003	......	0.0005	......	0.0002	......
4-6	0.0000	0.0003	0.0002	0.0003	0.0005	0.0003	0.0000	0.0003
	0.0003	......	0.0005	......	0.0008	......	0.0008	......
6–8	0.0000	0.0004	0.0003	0.0004	0.0006	0.0004	0.0000	0.0004
	0.0004	......	0.0007	......	0.0001	......	0.0004	......

GRINDING LIMITS FOR CYLINDRICAL PIECES

It is Brown and Sharpe practice to consider the hole as being standard, and the limits shown below are based on the standard hole. The grinding limits for holes apply to hardened pieces. The holes in soft pieces are chucked to standard diameter. It is possible that where both parts are hardened, closer limits may be necessary, assuming the parts are to be assembled without fitting.

RUNNING FITS—ORDINARY SPEEDS

These limits are satisfactory for shafts running under 600 revolutions per minute and under ordinary working conditions. Spindles for all purposes are to be considered as special cases.

To ½-inch diameter, inclusive.....	0.0005 to 0.001	Small
To 1-inch diameter, inclusive.....	0.00075 to 0.0015	Small
To 2-inch diameter, inclusive.....	0.0015 to 0.0025	Small
To 3½-inch diameter, inclusive....	0.002 to 0.003	Small
To 6-inch diameter, inclusive.....	0.0025 to 0.004	Small

RUNNING FITS—HIGH-SPEED, HEAVY-PRESSURE, AND ROCKER SHAFTS

These limits are satisfactory for shafts running more than 600 revolutions per minute and where the working conditions are severe. Spindles for all purposes are to be considered as special cases.

To ½-inch diameter, inclusive.....	0.0005 to 0.001	Small
To 1-inch diameter, inclusive.....	0.001 to 0.002	Small
To 2-inch diameter, inclusive.....	0.002 to 0.003	Small
To 3½-inch diameter, inclusive....	0.003 to 0.004	Small
To 6-inch diameter, inclusive.....	0.004 to 0.005	Small

SLIDING FITS

These limits are for shafts where a gear, clutch or other similar part slides on it continuously while the machine is in operation. These limits are the same as for "Running Fits—Ordinary Speeds."

To ½-inch diameter, inclusive	0.0005 to 0.001	Small
To 1-inch diameter, inclusive	0.00075 to 0.0015	Small
To 2-inch diameter, inclusive	0.0015 to 0.0025	Small
To 3½-inch diameter, inclusive	0.002 to 0.003	Small
To 6-inch diameter, inclusive	0.0025 to 0.004	Small

Standard Fits—Where the Load Is Not Heavy and Where the Part Is Keyed to the Shaft and Clamped Endwise with a Nut

These limits are suitable for light service only and where no fitting is to be done.

To ½-inch diameter, inclusive	Standard to 0.00025	Small
To 3½-inch diameter, inclusive	Standard to 0.0005	Small
To 6-inch diameter, inclusive	Standard to 0.00075	Small

These limits are to be used where it is desirable or essential that the parts fit together without play, and still be put together or taken apart without difficulty. Some fitting may be required and also some selecting may be necessary to attain the proper results.

To ½-inch diameter, inclusive	Standard to 0.00025	Large
To 3½-inch diameter, inclusive	Standard to 0.0005	Large
To 6-inch diameter, inclusive	Standard to 0.00075	Large

Driving Fits

For use where parts must fit tightly and where the location of the parts is such that they could not be put together if the drive was too great. These limits will apply where the assembly is permanent.

To ½-inch diameter, inclusive	Standard to 0.00025	Large
To 1-inch diameter, inclusive	0.0025 to 0.0005	Large
To 2-inch diameter, inclusive	0.0005 to 0.00075	Large
To 6-inch diameter, inclusive	0.0005 to 0.001	Large

Driving Fits

To be used where the assembly is permanent and the duty severe, and where there is room for the handling and driving of the parts.

To 2-inch diameter, inclusive	0.0005 to 0.001	Large
To 3½-inch diameter, inclusive	0.00075 to 0.00125	Large
To 6-inch diameter, inclusive	0.001 to 0.0015	Large

Forcing Fits

These limits may be used where parts are not expected to be taken apart and where service is very severe. This assembling is done under the arbor press for the smaller parts and under the hydraulic press for larger parts.

The method of forcing the parts together and the length of the parts will have influence on how large to leave the shaft.

To ½-inch diameter, inclusive.....	0.00075 to 0.001	Large
To 1-inch diameter, inclusive.....	0.001 to 0.002	Large
To 2-inch diameter, inclusive.....	0.002 to 0.003	Large
To 3½-inch diameter, inclusive....	0.003 to 0.004	Large
To 6-inch diameter, inclusive.....	0.004 to 0.005	Large

Shrinking Fits—for Pieces to Take Hardened Shells ⅜ Inch Thick and Less

To 1-inch diameter, inclusive.....	0.00025 to 0.0005	Large
To 2-inch diameter, inclusive.....	0.0005 to 0.00075	Large
To 3½-inch diameter, inclusive....	0.0005 to 0.001	Large
To 6-inch diameter, inclusive.....	0.001 to 0.0015	Large

Shrinking Fits—for Pieces to Take Shells, Etc., Having a Thickness of More than ⅜ Inch

To ½-inch diameter, inclusive.....	0.0005 to 0.001	Large
To 1-inch diameter, inclusive.....	0.001 to 0.002	Large
To 2-inch diameter, inclusive.....	0.002 to 0.003	Large
To 3½-inch diameter, inclusive....	0.003 to 0.004	Large
To 6-inch diameter, inclusive.....	0.004 to 0.005	Large

Grinding Limits for Holes

To 2-inch diameter, inclusive.....	Standard to 0.0005	Large
To 3½-inch diameter, inclusive....	Standard to 0.00075	Large
To 6-inch diameter, inclusive.....	Standard to 0.001	Large

BRITISH ENGINEERING STANDARDS ASSOCIATION[1]

British Standard Limits and Fits for Engineering

The basis of the tables herewith being a hole basis, the limiting dimensions of any hole of a particular quality and size remain unchanged, and varieties of fit are obtained by varying the actual dimensions of the shaft. The Association recognizes that exceptions to this rule are necessary in certain classes of work.

Table 19 gives both unilateral and bilateral limits of tolerance for holes. In the unilateral system, the nominal size is the low limit of the hole; in the bilateral system, the nominal size lies between the high and low limits of the hole. The Association recommends the use of the unilateral system as applied to cylindrical mating surfaces in cases where it does not conflict with predominating present practice.

Table 20 gives the recommended limits of tolerance for a standard series of graduated shafts suitable for pairing with either the unilateral or bilateral holes. Table 21 shows the numerical values of the limits of fit resulting from the assembly of any one of the standard shafts in a particular unilateral hole and a particular bilateral hole. The particular holes chosen for these numerical examples are identified by the symbols U and X (Table 19) respectively, and they have been selected because the tolerances on these holes are those most commonly employed. The numerical values of the limits of fit resulting from the assembly of the standard shafts in any of the other holes specified in the tables can be arrived at by simple arithmetical calculation.

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[1] Permission of British Engineering Standards Association.

The effect of transferring any standard shaft from a bilateral hole to a unilateral hole tends either to increase the clearance or to decrease the interference; in short, it makes the fit easier.

Table 19 provides four standard grades of workmanship for holes, in which **B** (unilateral) and **K** (bilateral) holes represent the most accurate grade, while **U** (unilateral) and **X** (bilateral) holes represent those most commonly employed. Unilateral holes **V**, **W**, and bilateral holes **Y**, **Z**, have larger tolerances.

Table 19 also provides for the use of three holes **A**, **G**, **H**, each with two positive limits of tolerance. These are called oversize holes. They are common to both the unilateral and bilateral systems, and are included in the tables to meet exceptional conditions.

The range of the tables is from 0 to approximately 25 inches (635 millimeters) in diameter. The nominal sizes are specified in ranges and the length of each range is such that at each change of range the tolerance increase on **U** and **X** holes is two ten-thousandths of an inch.

The table of shafts, which is common to the unilateral and bilateral systems, provides for a series of fourteen different fits with reference to any particular hole by progressively changing the disposition of the tolerance in relation to the nominal size. The tolerance itself remains unchanged for all shafts in the table from **F** to **M** inclusive. These shafts are of the same grade of workmanship as a **B** hole. Shafts **Q**, **R**, **S**, **T**, **TT** are given increasing tolerances because they are all considerably undersize and, therefore, provide increasing amounts of clearance when assembled in any hole.

The range of fits provided by the full series of shafts is divided into three main classes, which are defined as Interference, Transition and Clearance Fits. These terms are recommended for use when specifying a class of fit. Terms such as push fit, etc., which are in common use but have no numerically exact meaning, are not recommended, but their approximate application to the table has been indicated in the diagram in order that the new standards may be more readily applied to existing practice. When the exact nature of a fit has to be named, it is recommended that the symbols of the hole and shaft be used in combination, *for example*, **UR**, and marked on the assembly drawing in this form. The drawing of the hole and the drawing of the shaft can then be marked **U** and **R** respectively in combination with the nominal size, *for example*, in reference to the nominal size 1¾, 1¾ inches **U**, 1¾ inches **R**, or the limits of tolerance can be specified in figures if preferred.

The Association recommends, in the interests of uniformity and lucid terminology, that where different classes of fit have to be described in general terms, the following definitions should be employed:

1. "*Clearance fit*" where there is a positive allowance between the largest possible shaft and the smallest possible hole.

2. "*Interference fit*" where there is a negative allowance (obstruction) between the largest hole and the smallest shaft, the shaft being larger than the hole.

3. "*Transition fit*" covering cases between (1) and (2), *that is*, cases in which the limits admit of either clearance or interference fits being obtained.

Size Multiplier *m* and Range Factor *r*.—Values of *m*, the size multiplier, for nominal sizes from Zero to 25.29 inches (632.49 millimeters) and *r*, the range factor, are given respectively in the first column and the last line of the tables.

The limit values in the tables are found by multiplying together these quantities *m* and *r*, odd half-ten-thousandths being eliminated by subtracting such odd amounts from the products in which they occur, negative products thus becoming more negative.

EXAMPLE 1.—To find the limits for a 2¼-inch U hole.

The value of *m* corresponding with 2¼-inches is 8; see table on page 772.

The value of *r* for the high limit of U = 2 (in ten-thousandths of an inch).

The value of *r* for the low limit of U = 0. Hence required limits are + 0.0016 inch and + 0.

EXAMPLE 2.—To find the limits for a 6¼-inch X hole.

The value of *m* for 6¼-inches = 12.

The value of *r* for the high limit of X = +1.

The value of *r* for the low limit of X = −1.

Hence required limits are ± 0.0012.

EXAMPLE 3.—Assuming that the minimum hole passed by a plug limit gauge be 0.0003 inch greater than the tabular low limit for a 4½-inch X hole, what actual clearance will such a hole afford a 4½-inch R shaft when the latter is only 0.0002 inch below its tabular high limit?

The value of *m* for 4½ inches = 11.

The value of *r* for the low limit of X = −1.

The values of *r* for R = −0.3 and −0.5.

Hence minimum hole the gauge will

accept = 4½ inches − 0.0011 inch
+ 0.0003 inch
= 4½ inches − 0.0008 inch.

Actual size of shaft = 4½ inches − 0.0033 inch − 0.0002 inch.
= 4½ inches − 0.0035 inch.

Hence clearance = 0.0035 inch − 0.0008 inch = 0.0027 inch; which is (0.0003 + 0.0002) or 0.0005 inch greater than the figure given for minimum clearance in the Table of Fits, page 774.

Automatic and Air Gaging

Automatic gaging in the finishing of parts is almost entirely confined to grinding. The Heald method uses a "go" and "not go" gage applied to the work through the hollow work spindle. Bryant and Norton use electrical contacts to cut out the feeds when the correct size is reached. Landis uses a low-pressure air jet that strikes the work between two hard-faced shoes that form a V against the work. As the diameter of the work decreases the air nozzle approaches the work and builds up a back pressure that forces a mercury column into a contact that closes a solenoid circuit and withdraws the wheel from the work. Air gages are also used

TABLE 19.—BRITISH STANDARD LIMITS AND FITS FOR ENGINEERING
UNILATERAL, BILATERAL, AND OVERSIZE HOLES
BRITISH SYSTEM, IN INCHES

THE USE OF THE UNILATERAL SYSTEM AS APPLIED TO CYLINDRICAL MATING SURFACES IS RECOMMENDED IN CASES WHERE IT DOES NOT CONFLICT WITH PREDOMINATING PRESENT PRACTICE

(All dimensions except nominal sizes are expressed in thousandths of an inch)

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Size Multiplier	Nominal Sizes	Unilateral Holes (In which the low limit of the hole is nominal size.)								Bilateral Holes (In which the nominal size of the hole lies between the high and low limits.)			
		B		U		V		W		K		X	
m	Inches	H	L	H	L	H	L	H	L	H	L	H	L
3	0– 0.29	+0.3	0	+0.6	0	+1.2	0	+ 2.4	0	+0.1	−0.2	+0.3	−0.3
4	0.3– 0.59	+0.4	0	+0.8	0	+1.6	0	+ 3.2	0	+0.2	−0.2	+0.4	−0.4
5	0.6– 0.99	+0.5	0	+1.0	0	+2.0	0	+ 4.0	0	+0.2	−0.3	+0.5	−0.5
6	1.0– 1.49	+0.6	0	+1.2	0	+2.4	0	+ 4.8	0	+0.3	−0.3	+0.6	−0.6
7	1.5– 2.09	+0.7	0	+1.4	0	+2.8	0	+ 5.6	0	+0.3	−0.4	+0.7	−0.7
8	2.1– 2.79	+0.8	0	+1.6	0	+3.2	0	+ 6.4	0	+0.4	−0.4	+0.8	−0.8
9	2.8– 3.59	+0.9	0	+1.8	0	+3.6	0	+ 7.2	0	+0.4	−0.5	+0.9	−0.9
10	3.6– 4.49	+1.0	0	+2.0	0	+4.0	0	+ 8.0	0	+0.5	−0.5	+1.0	−1.0
11	4.5– 5.49	+1.1	0	+2.2	0	+4.4	0	+ 8.8	0	+0.5	−0.6	+1.1	−1.1
12	5.5– 6.59	+1.2	0	+2.4	0	+4.8	0	+ 9.6	0	+0.6	−0.6	+1.2	−1.2
13	6.6– 7.79	+1.3	0	+2.6	0	+5.2	0	+10.4	0	+0.6	−0.7	+1.3	−1.3
14	7.8 –9.09	+1.4	0	+2.8	0	+5.6	0	+11.2	0	+0.7	−0.7	+1.4	−1.4
15	9.1–10.49	+1.5	0	+3.0	0	+6.0	0	+12.0	0	+0.7	−0.8	+1.5	−1.5
16	10.5–11.99	+1.6	0	+3.2	0	+6.4	0	+12.8	0	+0.8	−0.8	+1.6	−1.6
17	12.0–13.59	+1.7	0	+3.4	0	+6.8	0	+13.6	0	+0.8	−0.9	+1.7	−1.7
18	13.6–15.29	+1.8	0	+3.6	0	+7.2	0	+14.4	0	+0.9	−0.9	+1.8	−1.8
19	15.3–17.09	+1.9	0	+3.8	0	+7.6	0	+15.2	0	+0.9	−1.0	+1.9	−1.9
20	17.1–18.99	+2.0	0	+4.0	0	+8.0	0	+16.0	0	+1.0	−1.0	+2.0	−2.0
21	19.0–20.99	+2.1	0	+4.2	0	+8.4	0	+16.8	0	+1.0	−1.1	+2.1	−2.1
22	21.0–23.09	+2.2	0	+4.4	0	+8.8	0	+17.6	0	+1.1	−1.1	+2.2	−2.2
23	23.1–25.29	+2.3	0	+4.6	0	+9.2	0	+18.4	0	+1.1	−1.2	+2.3	−2.3
Range Factor, r		+0.1	0	+0.2	0	+0.4	0	+ 0.8	0	+0.05	−0.05	+0.1	−0.1

TABLE 19.—BRITISH STANDARD LIMITS AND FITS FOR ENGINEERING UNILATERAL, BILATERAL, AND OVERSIZE HOLES BRITISH SYSTEM, IN INCHES.—*Continued*

1	2	15	16	17	18	19	20	21	22	23	24	25	26
Size Multiplier	Nominal Sizes	BILATERAL HOLES (In which the nominal size of the hole lies between the high and low limits.)				OVERSIZE HOLES (In which the low limit of the hole is larger than the nominal size.)						Non-Mating Holes and Shafts	
		Y		Z		A		G		H		J	
m	Inches	H	L	H	L	H	L	H	L	H	L	H	L
3	0–0.29	+0.6	−0.6	+1.2	−1.2	+1.2	+0.6	+1.8	+1.2	+2.4	+1.8	+3.0	−3.0
4	0.3–0.59	+0.8	−0.8	+1.6	−1.6	+1.6	+0.8	+2.4	+1.6	+3.2	+2.4	+4.0	−4.0
5	0.6–0.99	+1.0	−1.0	+2.0	−2.0	+2.0	+1.0	+3.0	+2.0	+4.0	+3.0	+5.0	−5.0
6	1.0–1.49	+1.2	−1.2	+2.4	−2.4	+2.4	+1.2	+3.6	+2.4	+4.8	+3.6	+6.0	−6.0
7	1.5–2.09	+1.4	−1.4	+2.8	−2.8	+2.8	+1.4	+4.2	+2.8	+5.6	+4.2	+7.0	−7.0
8	2.1–2.79	+1.6	−1.6	+3.2	−3.2	+3.2	+1.6	+4.8	+3.2	+6.4	+4.8	+8.0	−8.0
9	2.8–3.59	+1.8	−1.8	+3.6	−3.6	+3.6	+1.8	+5.4	+3.6	+7.2	+5.4	+9.0	−9.0
10	3.6–4.49	+2.0	−2.0	+4.0	−4.0	+4.0	+2.0	+6.0	+4.0	+8.0	+6.0	+10.0	−10.0
11	4.5–5.49	+2.2	−2.2	+4.4	−4.4	+4.4	+2.2	+6.6	+4.4	+8.8	+6.6	+11.0	−11.0
12	5.5–6.59	+2.4	−2.4	+4.8	−4.8	+4.8	+2.4	+7.2	+4.8	+9.6	+7.2	+12.0	−12.0
13	6.6–7.79	+2.6	−2.6	+5.2	−5.2	+5.2	+2.6	+7.8	+5.2	+10.4	+7.8	+13.0	−13.0
14	7.8–9.09	+2.8	−2.8	+5.6	−5.6	+5.6	+2.8	+8.4	+5.6	+11.2	+8.4	+14.0	−14.0
15	9.1–10.49	+3.0	−3.0	+6.0	−6.0	+6.0	+3.0	+9.0	+6.0	+12.0	+9.0	+15.0	−15.0
16	10.5–11.99	+3.2	−3.2	+6.4	−6.4	+6.4	+3.2	+9.6	+6.4	+12.8	+9.6	+16.0	−16.0
17	12.0–13.59	+3.4	−3.4	+6.8	−6.8	+6.8	+3.4	+10.2	+6.8	+13.6	+10.2	+17.0	−17.0
18	13.6–15.29	+3.6	−3.6	+7.2	−7.2	+7.2	+3.6	+10.8	+7.2	+14.4	+10.8	+18.0	−18.0
19	15.3–17.09	+3.8	−3.8	+7.6	−7.6	+7.6	+3.8	+11.4	+7.6	+15.2	+11.4	+19.0	−19.0
20	17.1–18.99	+4.0	−4.0	+8.0	−8.0	+8.0	+4.0	+12.0	+8.0	+16.0	+12.0	+20.0	−20.0
21	19.0–20.99	+4.2	−4.2	+8.4	−8.4	+8.4	+4.2	+12.6	+8.4	+16.8	+12.6	+21.0	−21.0
22	21.0–23.09	+4.4	−4.4	+8.8	−8.8	+8.8	+4.4	+13.2	+8.8	+17.6	+13.2	+22.0	−22.0
23	23.1–25.29	+4.6	−4.6	+9.2	−9.2	+9.2	+4.6	+13.8	+9.2	+18.4	+13.8	+23.0	−23.0
Range Factor, *r*		+0.2	−0.2	+0.4	−0.4	+0.4	+0.2	+0.6	+0.4	+0.8	+0.6	+1.0	−1.0

H = High limit of tolerance. **L** = Low limit of tolerance. The sign + or — below the symbols **H** and **L** indicates whether the limits are positive or negative.

TABLE 20.—BRITISH STANDARD LIMITS AND FITS FOR ENGINEERING

STANDARD SHAFTS

FOR USE WITH EITHER UNILATERAL, BILATERAL OR OVERSIZE HOLES

BRITISH SYSTEM—INCHES

THE USE OF THE UNILATERAL SYSTEM AS APPLIED TO CYLINDRICAL MATING SURFACES IS RECOMMENDED IN CASES WHERE IT DOES NOT CONFLICT WITH PREDOMINATING PRESENT PRACTICE

(All dimensions except nominal sizes are expressed in thousandths of an inch)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Size Multiplier	Nominal Sizes	F		E		D		C		B		K		L	
m	Inches	H	L	H	L	H	L	H	L	H	L	H	L	H	L
3	0– 0.29	+1.2	+0.9	+0.9	+0.6	+0.6	+0.3	+0.4	+0.1	+0.3	0	+0.1	−0.2	0	−0.3
4	0.3– 0.59	+1.6	+1.2	+1.2	+0.8	+0.8	+0.4	+0.6	+0.2	+0.4	0	+0.2	−0.2	0	−0.4
5	0.6– 0.99	+2.0	+1.5	+1.5	+1.0	+1.0	+0.5	+0.7	+0.2	+0.5	0	+0.2	−0.3	0	−0.5
6	1.0– 1.49	+2.4	+1.8	+1.8	+1.2	+1.2	+0.6	+0.9	+0.3	+0.6	0	+0.3	−0.3	0	−0.6
7	1.5– 2.09	+2.8	+2.1	+2.1	+1.4	+1.4	+0.7	+1.0	+0.3	+0.7	0	+0.3	−0.4	0	−0.7
8	2.1– 2.79	+3.2	+2.4	+2.4	+1.6	+1.6	+0.8	+1.2	+0.4	+0.8	0	+0.4	−0.4	0	−0.8
9	2.8– 3.59	+3.6	+2.7	+2.7	+1.8	+1.8	+0.9	+1.3	+0.4	+0.9	0	+0.4	−0.5	0	−0.9
10	3.6– 4.49	+4.0	+3.0	+3.0	+2.0	+2.0	+1.0	+1.5	+0.5	+1.0	0	+0.5	−0.5	0	−1.0
11	4.5– 5.49	+4.4	+3.3	+3.3	+2.2	+2.2	+1.1	+1.6	+0.5	+1.1	0	+0.5	−0.6	0	−1.1
12	5.5– 6.59	+4.8	+3.6	+3.6	+2.4	+2.4	+1.2	+1.8	+0.6	+1.2	0	+0.6	−0.6	0	−1.2
13	6.6– 7.79	+5.2	+3.9	+3.9	+2.6	+2.6	+1.3	+1.9	+0.6	+1.3	0	+0.6	−0.7	0	−1.3
14	7.8– 9.09	+5.6	+4.2	+4.2	+2.8	+2.8	+1.4	+2.1	+0.7	+1.4	0	+0.7	−0.7	0	−1.4
15	9.1–10.49	+6.0	+4.5	+4.5	+3.0	+3.0	+1.5	+2.2	+0.7	+1.5	0	+0.7	−0.8	0	−1.5
16	10.5–11.99	+6.4	+4.8	+4.8	+3.2	+3.2	+1.6	+2.4	+0.8	+1.6	0	+0.8	−0.8	0	−1.6
17	12.0–13.59	+6.8	+5.1	+5.1	+3.4	+3.4	+1.7	+2.5	+0.8	+1.7	0	+0.8	−0.9	0	−1.7
18	13.6–15.29	+7.2	+5.4	+5.4	+3.6	+3.6	+1.8	+2.7	+0.9	+1.8	0	+0.9	−0.9	0	−1.8
19	15.3–17.09	+7.6	+5.7	+5.7	+3.8	+3.8	+1.9	+2.8	+0.9	+1.9	0	+0.9	−1.0	0	−1.9
20	17.1–18.99	+8.0	+6.0	+6.0	+4.0	+4.0	+2.0	+3.0	+1.0	+2.0	0	+1.0	−1.0	0	−2.0
21	19.0–20.99	+8.4	+6.3	+6.3	+4.2	+4.2	+2.1	+3.1	+1.0	+2.1	0	+1.0	−1.1	0	−2.1
22	21.0–23.09	+8.8	+6.6	+6.6	+4.4	+4.4	+2.2	+3.3	+1.1	+2.2	0	+1.1	−1.1	0	−2.2
23	23.1–25.29	+9.2	+6.9	+6.9	+4.6	+4.6	+2.3	+3.4	+1.1	+2.3	0	+1.1	−1.2	0	−2.3
Range Factor, *r*		+0.4	+0.3	+0.3	+0.2	+0.2	+0.1	+0.15	+0.05	+0.1	0	+0.05	−0.05	0	−0.1

TABLE 20.—BRITISH STANDARD LIMITS AND FITS FOR ENGINEERING STANDARD SHAFTS.—*Continued*

1	2	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Size Multiplier	Nominal Sizes	P		M		Q		R		S		T		TT	
m	Inches	H	L	H	L	H	L	H	L	H	L	H	L	H	L
3	0–0.29	−0.2	−0.5	−0.3	−0.6	−0.5	−0.9	−0.9	−1.5	−1.5	−2.4	−2.4	−3.6	−3.6	−6.0
4	0.3–0.59	−0.2	−0.6	−0.4	−0.8	−0.6	−1.2	−1.2	−2.0	−2.0	−3.2	−3.2	−4.8	−4.8	−8.0
5	0.6–0.99	−0.3	−0.8	−0.5	−1.0	−0.8	−1.5	−1.5	−2.5	−2.5	−4.0	−4.0	−6.0	−6.0	−10.0
6	1.0–1.49	−0.3	−0.9	−0.6	−1.2	−0.9	−1.8	−1.8	−3.0	−3.0	−4.8	−4.8	−7.2	−7.2	−12.0
7	1.5–2.09	−0.4	−1.1	−0.7	−1.4	−1.1	−2.1	−2.1	−3.5	−3.5	−5.6	−5.6	−8.4	−8.4	−14.0
8	2.1–2.79	−0.4	−1.2	−0.8	−1.6	−1.2	−2.4	−2.4	−4.0	−4.0	−6.4	−6.4	−9.6	−9.5	−16.0
9	2.8–3.59	−0.5	−1.4	−0.9	−1.8	−1.4	−2.7	−2.7	−4.5	−4.5	−7.2	−7.2	−10.8	−10.8	−18.0
10	3.6–4.49	−0.5	−1.5	−1.0	−2.0	−1.5	−3.0	−3.0	−5.0	−5.0	−8.0	−8.0	−12.0	−12.0	−20.0
11	4.5–5.49	−0.6	−1.7	−1.1	−2.2	−1.7	−3.3	−3.3	−5.5	−5.5	−8.8	−8.8	−13.2	−13.2	−22.0
12	5.5–6.59	−0.6	−1.8	−1.2	−2.4	−1.8	−3.6	−3.6	−6.0	−6.0	−9.6	−9.6	−14.4	−14.4	−24.0
13	6.6–7.79	−0.7	−2.0	−1.3	−2.6	−2.0	−3.9	−3.9	−6.5	−6.5	−10.4	−10.4	−15.6	−15.6	−26.0
14	7.8–9.09	−0.7	−2.1	−1.4	−2.8	−2.1	−4.2	−4.2	−7.0	−7.0	−11.2	−11.2	−16.8	−16.8	−28.0
15	9.1–10.49	−0.8	−2.3	−1.5	−3.0	−2.3	−4.5	−4.5	−7.5	−7.5	−12.0	−12.0	−18.0	−18.0	−30.0
16	10.5–11.99	−0.8	−2.4	−1.6	−3.2	−2.4	−4.8	−4.8	−8.0	−8.0	−12.8	−12.8	−19.2	−19.2	−32.0
17	12.0–13.59	−0.9	−2.6	−1.7	−3.4	−2.6	−5.1	−5.1	−8.5	−8.5	−13.6	−13.6	−20.4	−20.4	−34.0
18	13.6–15.29	−0.9	−2.7	−1.8	−3.6	−2.7	−5.4	−5.4	−9.0	−9.0	−14.4	−14.4	−21.6	−21.6	−36.0
19	15.3–17.09	−1.0	−2.9	−1.9	−3.8	−2.9	−5.7	−5.7	−9.5	−9.5	−15.2	−15.2	−22.8	−22.8	−38.0
20	17.1–18.99	−1.0	−3.0	−2.0	−4.0	−3.0	−6.0	−6.0	−10.0	−10.0	−16.0	−16.0	−24.0	−24.0	−40.0
21	19.0–20.99	−1.1	−3.2	−2.1	−4.2	−3.2	−6.3	−6.3	−10.5	−10.5	−16.8	−16.8	−25.2	−25.2	−42.0
22	21.0–23.09	−1.1	−3.3	−2.2	−4.4	−3.3	−6.6	−6.6	−11.0	−11.0	−17.6	−17.6	−26.4	−26.4	−44.0
23	23.1–25.29	−1.2	−3.5	−2.3	−4.6	−3.5	−6.9	−6.9	−11.5	−11.5	−18.4	−18.4	−27.6	−27.6	−46.0
Range Factor, *r*		−0.05	−0.15	−0.1	−0.2	−0.15	−0.3	−0.3	−0.5	−0.5	−0.8	−0.8	−1.2	−1.2	−2.0

H = High limit of tolerance. **L** = Low limit of tolerance. The sign + or — below the symbols **H** and **L** indicates whether the limits are positive or negative.

TABLE 21.—BRITISH STANDARD LIMITS AND FITS FOR ENGINEERING FITS OF STANDARD SHAFTS IN "U" AND BRITISH SYSTEM—INCHES

The use of the unilateral system as applied to cylindrical mating surfaces is recommended in cases where it does not conflict with predominating present practice

(All dimensions except nominal sizes are expressed in thousandths of an inch)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Size Multiplier	Nominal Sizes	STANDARD SHAFTS IN UNILATERAL "U" HOLES													
m	Inches	UF	UE	UD	UC	UB	UK	UL	UP	UM	UQ	UR	US	UT	UTT
3	0– 0.29	−1.2 −0.3	−0.9 0	−0.6 +0.3	−0.4 +0.5	−0.3 +0.6	−0.1 +0.8	0 +0.9	+0.2 +1.1	+0.3 +1.2	+ 0.5 + 1.5	+ 0.9 + 2.1	+ 1.5 + 3.0	+ 2.4 + 4.2	+ 3.6 + 6.6
4	0.3– 0.59	−1.6 −0.4	−1.2 0	−0.8 +0.4	−0.6 +0.6	−0.4 +0.8	−0.2 +1.0	0 +1.2	+0.2 +1.4	+0.4 +1.6	+ 0.6 + 2.0	+ 1.2 + 2.8	+ 2.0 + 4.0	+ 3.2 + 5.6	+ 4.8 + 8.8
5	0.6– 0.99	−2.0 −0.5	−1.5 0	−1.0 +0.5	−0.7 +0.8	−0.5 +1.0	−0.2 +1.3	0 +1.5	+0.3 +1.8	+0.5 +2.0	+ 0.8 + 2.5	+ 1.5 + 3.5	+ 2.5 + 5.0	+ 4.0 + 7.0	+ 6.0 +11.0
6	1.0– 1.49	−2.4 −0.6	−1.8 0	−1.2 +0.6	−0.9 +0.9	−0.6 +1.2	−0.3 +1.5	0 +1.8	+0.3 +2.1	+0.6 +2.4	+ 0.9 + 3.0	+ 1.8 + 4.2	+ 3.0 + 6.0	+ 4.8 + 8.4	+ 7.2 +13.2
7	1.5– 2.09	−2.8 −0.7	−2.1 0	−1.4 +0.7	−1.0 +1.1	−0.7 +1.4	−0.3 +1.8	0 +2.1	+0.4 +2.5	+0.7 +2.8	+ 1.1 + 3.5	+ 2.1 + 4.9	+ 3.5 + 7.0	+ 5.6 + 9.8	+ 8.4 +15.4
8	2.1– 2.79	−3.2 −0.8	−2.4 0	−1.6 +0.8	−1.2 +1.2	−0.8 +1.6	−0.4 +2.0	0 +2.4	+0.4 +2.8	+0.8 +3.2	+ 1.2 + 4.0	+ 2.4 + 5.6	+ 4.0 + 8.0	+ 6.4 +11.2	+ 9.6 +17.6
9	2.8– 3.59	−3.6 −0.9	−2.7 0	−1.8 +0.9	−1.3 +1.4	−0.9 +1.8	−0.4 +2.3	0 +2.7	+0.5 +3.2	+0.9 +3.6	+ 1.4 + 4.5	+ 2.7 + 6.3	+ 4.5 + 9.0	+ 7.2 +12.6	+10.8 +19.8
10	3.6– 4.49	−4.0 −1.0	−3.0 0	−2.0 +1.0	−1.5 +1.5	−1.0 +2.0	−0.5 +2.5	0 +3.0	+0.5 +3.5	+1.0 +4.0	+ 1.5 + 5.0	+ 3.0 + 7.0	+ 5.0 +10.0	+ 8.0 +14.0	+12.0 +22.0
11	4.5– 5.49	−4.4 −1.1	−3.3 0	−2.2 +1.1	−1.6 +1.7	−1.1 +2.2	−0.5 +2.8	0 +3.3	+0.6 +3.9	+1.1 +4.4	+ 1.7 + 5.5	+ 3.3 + 7.7	+ 5.5 +11.0	+ 8.8 +15.4	+13.2 +24.2

TABLE 21.—BRITISH STANDARD LIMITS AND FITS FOR ENGINEERING FITS OF STANDARD SHAFTS.—*Continued*

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Size Multiplier	Nominal Sizes	STANDARD SHAFTS IN UNILATERAL "U" HOLES													
m	Inches	UF	UE	UD	UC	UB	UK	UL	UP	UM	UQ	UR	US	UT	UTT
12	5.5– 6.59	−4.8 −1.2	−3.6 0	−2.4 +1.2	−1.8 +1.8	−1.2 +2.4	−0.6 +3.0	0 +3.6	+0.6 +4.2	+1.2 +4.8	+ 1.8 + 6.0	+ 3.6 + 8.4	+ 6.0 +12.0	+ 9.6 +16.8	+14.4 +26.4
13	6.6– 7.79	−5.2 −1.3	−3.9 0	−2.6 +1.3	−1.9 +2.0	−1.3 +2.6	−0.6 +3.3	0 +3.9	+0.7 +4.6	+1.3 +5.2	+ 2.0 + 6.5	+ 3.9 + 9.1	+ 6.5 +13.0	+10.4 +18.2	+15.6 +28.6
14	7.8– 9.09	−5.6 −1.4	−4.2 0	−2.8 +1.4	−2.1 +2.1	−1.4 +2.8	−0.7 +3.5	0 +4.2	+0.7 +4.9	+1.4 +5.6	+ 2.1 + 7.0	+ 4.2 + 9.8	+ 7.0 +14.0	+11.2 +19.6	+16.8 +30.8
15	9.1–10.49	−6.0 −1.5	−4.5 0	−3.0 +1.5	−2.2 +2.3	−1.5 +3.0	−0.7 +3.8	0 +4.5	+0.8 +5.3	+1.5 +6.0	+ 2.3 + 7.5	+ 4.5 +10.5	+ 7.5 +15.0	+12.0 +21.0	+18.0 +33.0
16	10.5–11.99	−6.4 −1.6	−4.8 0	−3.2 +1.6	−2.4 +2.4	−1.6 +3.2	−0.8 +4.0	0 +4.8	+0.8 +5.6	+1.6 +6.4	+ 2.4 + 8.0	+ 4.8 +11.2	+ 8.0 +16.0	+12.8 +22.4	+19.2 +35.2
17	12.0–13.59	−6.8 −1.7	−5.1 0	−3.4 +1.7	−2.5 +2.6	−1.7 +3.4	−0.8 +4.3	0 +5.1	+0.9 +6.0	+1.7 +6.8	+ 2.6 + 8.5	+ 5.1 +11.9	+ 8.5 +17.0	+13.6 +23.8	+20.4 +37.4
18	13.6–15.29	−7.2 −1.8	−5.4 0	−3.6 +1.8	−2.7 +2.7	−1.8 +3.6	−0.9 +4.5	0 +5.4	+0.9 +6.3	+1.8 +7.2	+ 2.7 + 9.0	+ 5.4 +12.6	+ 9.0 +18.0	+14.4 +25.2	+21.6 +39.6
19	15.3–17.09	−7.6 −1.9	−5.7 0	−3.8 +1.9	−2.8 +2.9	−1.9 +3.8	−0.9 +4.8	0 +5.7	+1.0 +6.7	+1.9 +7.6	+ 2.9 + 9.5	+ 5.7 +13.3	+ 9.5 +19.0	+15.2 +26.6	+22.8 +41.8
20	17.1–18.99	−8.0 −2.0	−6.0 0	−4.0 +2.0	−3.0 +3.0	−2.0 +4.0	−1.0 +5.0	0 +6.0	+1.0 +7.0	+2.0 +8.0	+ 3.0 +10.0	+ 6.0 +14.0	+10.0 +20.0	+16.0 +28.0	+24.0 +44.0
21	19.0–20.99	−8.4 −2.1	−6.3 0	−4.2 +2.1	−3.1 +3.2	−2.1 +4.2	−1.0 +5.3	0 +6.3	+1.1 +7.4	+2.1 +8.4	+ 3.2 +10.5	+ 6.3 +14.7	+10.5 +21.0	+16.8 +29.4	+25.2 +46.2
22	21.0–23.09	−8.8 −2.2	−6.6 0	−4.4 +2.2	−3.3 +3.3	−2.2 +4.4	−1.1 +5.5	0 +6.6	+1.1 +7.7	+2.2 +8.8	+ 3.3 +11.0	+ 6.6 +15.4	+11.0 +22.0	+17.6 +30.8	+26.4 +48.4
23	23.1–25.29	−9.2 −2.3	−6.9 0	−4.6 +2.3	−3.4 +3.5	−2.3 +4.6	−1.1 +5.8	0 +6.9	+1.2 +8.1	+2.3 +9.2	+ 3.5 +11.5	+ 6.9 +16.1	+11.5 +23.0	+18.4 +32.2	+27.6 +50.6

+ = Clearance. — = Interference.

The upper figures in each square represent the minimum, the lower figures the maximum, limit of fit.

TABLE 21.—BRITISH STANDARD LIMITS AND FITS FOR ENGINEERING FITS OF STANDARD SHAFTS.—*Continued*

1	2	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Size Multiplier	Nominal Sizes	STANDARD SHAFTS IN BILATERAL "X" HOLES													
m	Inches	XF	XE	XD	XC	XB	XK	XL	XP	XM	XQ	XR	XS	XT	XTT
3	0– 0.29	− 1.5 − 0.6	−1.2 −0.3	−0.9 0	−0.7 +0.2	−0.6 +0.3	−0.4 +0.5	−0.3 +0.6	−0.1 +0.8	0 +0.9	+0.2 +1.2	+ 0.6 + 1.8	+ 1.2 + 2.7	+ 2.1 + 3.9	+ 3.3 + 6.3
4	0.3– 0.59	− 2.0 − 0.8	−1.6 −0.4	−1.2 0	−1.0 +0.2	−0.8 +0.4	−0.6 +0.6	−0.4 +0.8	−0.2 +1.0	0 +1.2	+0.2 +1.6	+ 0.8 + 2.4	+ 1.6 + 3.6	+ 2.8 + 5.2	+ 4.4 + 8.4
5	0.6– 0.99	− 2.5 − 1.0	−2.0 −0.5	−1.5 0	−1.2 +0.3	−1.0 +0.5	−0.7 +0.8	−0.5 +1.0	−0.2 +1.3	0 +1.5	+0.3 +2.0	+ 1.0 + 3.0	+ 2.0 + 4.5	+ 3.5 + 6.5	+ 5.5 +10.5
6	1.0– 1.49	− 3.0 − 1.2	−2.4 −0.6	−1.8 0	−1.5 +0.3	−1.2 +0.6	−0.9 +0.9	−0.6 +1.2	−0.3 +1.5	0 +1.8	+0.3 +2.4	+ 1.2 + 3.6	+ 2.4 + 5.4	+ 4.2 + 7.8	+ 6.6 +12.6
7	1.5– 2.09	− 3.5 − 1.4	−2.8 −0.7	−2.1 0	−1.7 +0.4	−1.4 +0.7	−1.0 +1.1	−0.7 +1.4	−0.3 +1.8	0 +2.1	+0.4 +2.8	+ 1.4 + 4.2	+ 2.8 + 6.3	+ 4.9 + 9.1	+ 7.7 +14.7
8	2.1– 2.79	− 4.0 − 1.6	−3.2 −0.8	−2.4 0	−2.0 +0.4	−1.6 +0.8	−1.2 +1.2	−0.8 +1.6	−0.4 +2.0	0 +2.4	+0.4 +3.2	+ 1.6 + 4.8	+ 3.2 + 7.2	+ 5.6 +10.4	+ 8.8 +16.8
9	2.8– 3.59	− 4.5 − 1.8	−3.6 −0.9	−2.7 0	−2.2 +0.5	−1.8 +0.9	−1.3 +1.4	−0.9 +1.8	−0.4 +2.3	0 +2.7	+0.5 +3.6	+ 1.8 + 5.4	+ 3.6 + 8.1	+ 6.3 +11.7	+ 9.9 +18.9
10	3.6– 4.49	− 5.0 − 2.0	−4.0 −1.0	−3.0 0	−2.5 +0.5	−2.0 +1.0	−1.5 +1.5	−1.0 +2.0	−0.5 +2.5	0 +3.0	+0.5 +4.0	+ 2.0 + 6.0	+ 4.0 + 9.0	+ 7.0 +13.0	+11.0 +21.0
11	4.5– 5.49	− 5.5 − 2.2	−4.4 −1.1	−3.3 0	−2.7 +0.6	−2.2 +1.1	−1.6 +1.7	−1.1 +2.2	−0.5 +2.8	0 +3.3	+0.6 +4.4	+ 2.2 + 6.6	+ 4.4 + 9.9	+ 7.7 +14.3	+12.1 +23.1
12	5.5– 6.59	− 6.0 − 2.4	−4.8 −1.2	−3.6 0	−3.0 +0.6	−2.4 +1.2	−1.8 +1.8	−1.2 +2.4	−0.6 +3.0	0 +3.6	+0.6 +4.8	+ 2.4 + 7.2	+ 4.8 +10.8	+ 8.4 +15.6	+13.2 +25.2
13	6.6– 7.79	− 6.5 − 2.6	−5.2 −1.3	−3.9 0	−3.2 +0.7	−2.6 +1.3	−1.9 +2.0	−1.3 +2.6	−0.6 +3.3	0 +3.9	+0.7 +5.2	+ 2.6 + 7.8	+ 5.2 +11.7	+ 9.1 +16.9	+14.3 +27.3
14	7.8– 9.09	− 7.0 − 2.8	−5.6 −1.4	−4.2 0	−3.5 +0.7	−2.8 +1.4	−2.1 +2.1	−1.4 +2.8	−0.7 +3.5	0 +4.2	+0.7 +5.6	+ 2.8 + 8.4	+ 5.6 +12.6	+ 9.8 +18.2	+15.4 +29.4

TABLE 21.—BRITISH STANDARD LIMITS AND FITS FOR ENGINEERING FITS OF STANDARD SHAFTS.—*Continued*

1	2	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Size Multi-plier	Nominal Sizes	STANDARD SHAFTS IN BILATERAL "X" HOLES													
m	Inches	XF	XE	XD	XC	XB	XK	XL	XP	XM	XQ	XR	XS	XT	XTT
15	9.1–10.49	− 7.5 − 3.0	−6.0 −1.5	−4.5 0	−3.7 +0.8	−3.0 +1.5	−2.2 +2.3	−1.5 +3.0	−0.7 +3.8	0 +4.5	+0.8 +6.0	+ 3.0 + 9.0	+ 6.0 +13.5	+10.5 +19.5	+16.5 +31.5
16	10.5–11.99	− 8.0 − 3.2	−6.4 −1.6	−4.8 0	−4.0 +0.8	−3.2 +1.6	−2.4 +2.4	−1.6 +3.2	−0.8 +4.0	0 +4.8	+0.8 +6.4	+ 3.2 + 9.6	+ 6.4 +14.4	+11.2 +20.8	+17.6 +33.6
17	12.0–13.59	− 8.5 − 3.4	−6.8 −1.7	−5.1 0	−4.2 +0.9	−3.4 +1.7	−2.5 +2.6	−1.7 +3.4	−0.8 +4.3	0 +5.1	+0.9 +6.8	+ 3.4 +10.2	+ 6.8 +15.3	+11.9 +22.1	+18.7 +35.7
18	13.6–15.29	− 9.0 − 3.6	−7.2 −1.8	−5.4 0	−4.5 +0.9	−3.6 +1.8	−2.7 +2.7	−1.8 +3.6	−0.9 +4.5	0 +5.4	+0.9 +7.2	+ 3.6 +10.8	+ 7.2 +16.2	+12.6 +23.4	+19.8 +37.8
19	15.3–17.09	− 9.5 − 3.8	−7.6 −1.9	−5.7 0	−4.7 +1.0	−3.8 +1.9	−2.8 +2.9	−1.9 +3.8	−0.9 +4.8	0 +5.7	+1.0 +7.6	+ 3.8 +11.4	+ 7.6 +17.1	+13.3 +24.7	+20.9 +39.9
20	17.1–18.99	−10.0 − 4.0	−8.0 −2.0	−6.0 0	−5.0 +1.0	−4.0 +2.0	−3.0 +3.0	−2.0 +4.0	−1.0 +5.0	0 +6.0	+1.0 +8.0	+ 4.0 +12.0	+ 8.0 +18.0	+14.0 +26.0	+22.0 +42.0
21	19.0–20.99	−10.5 − 4.2	−8.4 −2.1	−6.3 0	−5.2 +1.1	−4.2 +2.1	−3.1 +3.2	−2.1 +4.2	−1.0 +5.3	0 +6.3	+1.1 +8.4	+ 4.2 +12.6	+ 8.4 +18.9	+14.7 +27.3	+23.1 +44.1
22	21.0–23.09	−11.0 − 4.4	−8.8 −2.2	−6.6 0	−5.5 +1.1	−4.4 +2.2	−3.3 +3.3	−2.2 +4.4	−1.1 +5.5	0 +6.6	+1.1 +8.8	+ 4.4 +13.2	+ 8.8 +19.8	+15.4 +28.6	+24.2 +46.2
23	23.1–25.29	−11.5 − 4.6	−9.2 −2.3	−6.9 0	−5.7 +1.2	−4.6 +2.3	−3.4 +3.5	−2.3 +4.6	−1.1 +5.8	0 +6.9	+1.2 +9.2	+ 4.6 +13.8	+ 9.2 +20.7	+16.1 +29.9	+25.3 +48.3

+ = Clearance
− = Interference.
The upper figures in each square represent the minimum, the lower figures the maximum, limit of fit.

in inspection work, the back pressure showing on a dial gage. These are set with master pieces so that a variation of about 5 pounds on the gage, (about 1 in. on the dial) may mean only 0.001 inch in the piece. Such gages do not actually measure but only indicate when the work is within the desired tolerance.

Machines have also been built to inspect such complicated pieces as cam shafts for V-8 engines. A conveyor carries the cam shaft past gages that check each dimension. If any tolerance is exceeded, the part is marked automatically, and the cam shaft goes to the rejected pile when it reaches the end of the conveyor.

PRESS AND SHRINK FITS

Press fits continue to be widely used in building many classes of machinery. The railroads are probably the greatest users of this method of holding parts together, as practiced in fitting car, truck and driving wheels on their axles and in holding crankpins in driving-wheel bosses. The methods used in railroad shops are the result of long years of experience by practical mechanics, who have attained great skill in handling this kind of work. A careful study of the methods and data given under Press Fit Practices, beginning on page 1177, will be found helpful in many lines of work besides that of the railroad.

Although inside micrometers are recommended for the close measurement of holes into which axles, crankpins, or shafts of any kind are to be forced, the use of calipers or pin gages, as shown on pages 721 to 724, has proved very accurate when the directions given are carefully followed.

With the hole surrounded by a heavy hub, it requires less allowance than the rule-of-thumb one-thousandth of an inch per inch of diameter to secure a good fit. With both shaft and hole round and smooth, one-half of this allowance will usually give a good fit. Surface finish and roundness are of great importance. With both surfaces ground smoothly it has been found that the parts could be forced together and separated, several times, with little appreciable difference in the pressure required.

In this connection it is suggested that the railroad practice of including a slight taper at one end of the fitted surface be carefully considered. This is mentioned in the fitting of both axles and crankpins, on pages 1178 and 1181.

As has been pointed out many times, it is a mistake to assume that the greater the difference in diameter the tighter will be the fit. This is only true up to the point where the distortion of the member containing the hole does not go beyond the elastic limit of the material. When this happens, the hole stretches and the fit is less tight than it would be if the force allowance was considerably less.

A careful study of Tables 7 to 13 inclusive will prevent glaring errors being made in selecting allowances for press fits.

Shrink Fits

As in press fits the experience of the railroads in shrink fits will be found very helpful. In view of the number of locomotive tires in use on locomotives and cars, it is doubtful that any other industry makes an equal number of shrink fits, certainly not in the sizes which are common practice on modern railroads.

Pages 1174 to 1176 contain much information on the shrinking of tires. Here it will be noted that the amount of shrinkage is about the rule-of-thumb amount of one-thousandth inch per inch of diameter for both truck and driving-wheel tires. The present practice is to have retaining rings in addition to the shrink fit, to prevent side movement of the tire when heated by excessive braking.

Taper Fits

In fitting such parts as turbine and generator couplings, press and shrink fits on tapers are often used. Table 22 offers a convenient source for this essential information. Even a taper as great as 3 inches to the foot may be used on turbine or generator work in order to prevent the coupling from sticking when it is pulled on tight with a fine-thread nut on the shaft.

In the table, the first vertical column gives the size of the hole in inches; the second gives the allowance for a press fit or, in other words, the oversize of the stock. The top horizontal line shows the series of tapers per foot; the remaining lines give the *length* to allow for tightening in both thousandths and fractions of an inch, in order to make it usable even by shops that do not have micrometers in their equipment.

EXAMPLE 1.—It is required to fit in 6-inch coupling on a turbine spindle with a $2\frac{1}{2}$-inch taper per foot of length. The standard diameter allowance for a 6-inch press fit is 0.009 inch. Enter the table at 6-inch size of hole, follow horizontally to the vertical column under $2\frac{1}{2}$ inches taper per foot. This gives 0.045 inch in decimals or $\frac{3}{64}$ inch in a fraction to the nearest sixty-fourth.

EXAMPLE 2.—It is required to fit a 6-inch diameter crankpin having a $\frac{1}{16}$ inch per foot taper. The allowance for press would again be 0.009 inch. Follow the horizontal column headed by 6-inch size of hole to the vertical column headed by $\frac{1}{16}$-inch taper per foot of length. The allowance here is 1.728 inches or $1\frac{47}{64}$ inches to the nearest sixty-fourth.

Expansion Fits[1]

Expansion fits are made by cooling the inner member, which is larger than the hole into which it goes, so that it will enter the hole and be tight when it warms up to room temperature. This is used where it is not practicable to heat the outer member, as in shrink fits. A common use is in fastening the hard exhaust valve seats used in gasoline motors. Either dry ice (solid carbon dioxide), which becomes a gas at −110°F., or liquid air (−310°F.) is used. These give a cooling range of 180 and 380°F. at room temperature.

Approximate contraction of different metals is given in Table 23, which shows that a $2\frac{1}{2}$-inch brass bushing will contract 2.5×0.0031 or 0.0077 inch in liquid air or 0.00375 inch with dry ice; this would

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[1] Data from United States Bureau of Standards, Linde Air Products, and others.

TABLE 22.—LENGTH OF PRESS AND SHRINK FITS ON TAPERS*

Size of Hole, in Inches	Allowance for Press Fits, in inches	Taper per Foot of Length, in Inches													
		1/16	1/8	3/16	1/4	3/8	1/2	5/8	3/4	1	1 1/4	1 1/2	2	2 1/2	3
1	0.002	0.384 25/64	0.192 3/16+	0.128 1/8+	0.096 3/32+	0.064 1/16+	0.048 3/64+	0.040 3/64−	0.032 1/32+	0.024	0.020	0.016 1/64+	0.012 1/64−	0.010 1/64−	0.008
2	0.004	0.768 49/64+	0.384 25/64−	0.256 1/4+	0.192 3/16+	0.128 1/8+	0.096 3/32+	0.080 5/64+	0.064 1/16+	0.048 3/64+	0.040 3/64−	0.032 1/32+	0.024 1/32−	0.020 1/64+	0.016 1/64+
3	0.0055	1.056 1 1/16	0.528 17/32−	0.352 23/64−	0.264 17/64−	0.176 11/64+	0.132 1/8+	0.110 7/64+	0.088 3/32−	0.066 1/16+	0.055 1/16−	0.044 3/64−	0.033 1/32+	0.027 1/32−	0.022 1/64+
4	0.007	1.344 1 11/32	0.672 43/64	0.448 29/64−	0.336 21/64+	0.224 7/32+	0.168 11/64−	0.140 9/64	0.112 7/64+	0.084 5/64+	0.070 5/64−	0.056 1/16−	0.042 3/64−	0.035 1/32+	0.028 1/32−
5	0.008	1.536 1 17/32+	0.768 49/64+	0.512 33/64−	0.382 25/64−	0.256 1/4+	0.192 3/16+	0.163 11/64−	0.128 1/8+	0.096 3/32+	0.081+ 5/64+	0.064 1/8+	0.048 3/64+	0.041 3/64−	0.032 1/32+
6	0.009	1.728 1 47/64+	0.864 55/64+	0.576 37/64	0.432 7/16−	0.288 9/32+	0.216 7/32−	0.180 3/16−	0.144 9/64+	0.108 7/64+	0.090 3/32−	0.072 5/64−	0.054 3/64+	0.045 3/64−	0.036 1/32+
7	0.010	1.920 1 59/64	0.960 61/64+	0.640 41/64	0.480 31/64−	0.320 21/64−	0.240 15/64+	0.200 13/64+	0.170 11/64−	0.120 1/8+	0.100 3/32+	0.085 3/32−	0.060 1/16−	0.050 3/64+	0.043 3/64−
8	0.011	2.112 2 7/64+	1.056 1 1/16−	0.704 45/64	0.528 17/32−	0.352 23/64−	0.264 17/64	0.220 7/32+	0.176 11/64+	0.132 9/64−	0.110 7/64+	0.088 5/64+	0.064 1/16+	0.055 1/16−	0.044 3/64−
9	0.012	2.304 2 19/16+	1.152 1 5/32+	0.768 49/64+	0.576 37/64−	0.384 25/64−	0.288 9/32+	0.240 1/4−	0.192 3/16+	0.144 9/64+	0.120 1/8−	0.096 3/32+	0.072 5/64−	0.048 3/64+	0.048 3/64+
10	0.012	2.304 2 19/64+	1.152 1 5/32+	0.768 49/64+	0.576 37/64−	0.384 25/64−	0.288 9/32+	0.240 1/4−	0.192 3/16+	0.144 9/64+	0.120 1/8−	0.096 3/32+	0.072 5/64−	0.060 1/16−	0.048 3/64+
12	0.013	2.496 2 1/2−	1.248 1 1/4−	0.832 53/64	0.624 5/8	0.416 27/64−	0.312 5/16	0.260 17/64	0.208 13/64	0.156 5/32	0.130 1/8+	0.104 7/64−	0.078 5/64	0.065 1/16+	0.052 3/64+

* G. T. King.

make its diameter 2.4923 inches or 2.49725 inches, depending upon which was used. Smaller fit allowances are needed than in shrink fits.

To find the difference in size of the mating parts, subtract the allowances in Table 24 from the contraction obtained from Table 23. This gives the diameter of the brass bushing as 2.0057 inches for liquid air or 2.00175 inches for dry ice, if the hole is bored 2 inches, or holes 2.4943 inches or 2.49925 inches if the bushing is turned exactly 2½ inches. On small work, fits can be made by heating the outer member in boiling water in addition to cooling the inner piece. Table 23 shows the expansion due to the heat of the water over room temperature. These are called "compound fits."

TABLE 23.—LINEAR CHANGE IN METALS FOR SPECIFIED TEMPERATURE CHANGES (APPROXIMATE)

Metal	Contraction per Inch of Length or Diameter from Room Temperature (70°F.)		Expansion per Inch from Room Temperature to 212°F. (Heat to Boiling Water)
	With Liquid Air (−310°F.)	With Solid CO_2 (−110°F.)	
Aluminum	0.0038	0.0018	0.0018
Brass	0.0031	0.0015	0.0015
Bronze	0.0038	0.0018	0.0014
Cast iron	0.0018	0.0008	0.0008
Copper	0.0029	0.0014	0.0012
Monel	0.0025	0.0012	0.0011
Nickel	0.0021	0.0010	0.0010
Steel	0.0020	0.0009	0.0008

TABLE 24.—ALLOWANCES OR TOLERANCES FOR SLIDING FITS

Fit Diameter, in Inches	Allowance in Inches Close	Moderate
½	0.00025	to 0.0005
1	0.0005	to 0.001
2	0.001	to 0.002
3½	0.002	to 0.0035
6	0.003	to 0.005

SHRINKING MACHINE PARTS WITH DRY ICE

Shrinking machine parts by the use of dry ice includes details which the average machine shop employee may not be familiar with. Take a shaft made of soft steel, 12 inches in diameter, to be shrunk with the use of dry ice, so that it can be pressed into a machined part, which, when the shaft has been allowed to cool to normal temperature after freezing, will make the two parts fit together as though made of one piece. If the shaft, which has a coefficient of expansion of 0.0000063 in., is reduced in temperature by 100 F., it will have shrunk approximately 0.00756 inch in diameter. This is found by multiplying the diameter, 12 inches, by the drop in temperature, 100°F., and then by the coefficient.

To determine the reduction in temperature to which a part must be subjected to obtain a desired shrinkage, divide the amount of shrinkage needed by the product obtained through multiplying the diameter by the coefficient of expansion. To shrink a 12-inch diameter shaft of soft steel 0.010 inch, the desired shrinkage is divided by 12 times the coefficient (0.0000063), resulting in about 133°F. This is the necessary drop in temperature to obtain the 0.01 inch shrinkage. It is necessary to know the specific heat, as well as the coefficient, of the particular metal to be shrunk. The coefficients of expansion and specific heat for various metals are given here for ready reference.

The formula employed, knowing the specific heat and the coefficient, is the following: Multiply specific heat by the weight of the material to be shrunk, and the resultant product by the needed temperature drop. Divide the result by 250, which is the number of B.t.u. in dry ice at low temperatures. This will give the weight in pounds of dry ice necessary.

Metal	Coef. of Expansion	Specific Heat
Aluminum	0.0000128	0.207
Brass, cast	0.0000104	0.088
rolled	0.0000107	0.090
Bronze	0.0000094	0.104
Copper	0.0000923	0.0915
Iron, pure	0.0000065	0.101
Steel, soft	0.0000063	0.107
hard	0.0000056	0.104
Nickel silver	0.0000102	0.095

Alcohol can be used in conjunction with dry ice to speed up the rate of heat transfer in a part being shrunk, by using a watertight container. The part is placed in this container; alcohol is poured over the piece and chunks of dry ice are dropped into the liquid. The alcohol causes the dry ice to boil, assists heat transfer, and causes the part to be cooled in a shorter time.

SECTION XVII

TAPERS AND DOVETAILS

MEASURING TAPERS

An Accurate Taper Gage

The gage illustrated in Fig. 1 is an exceedingly accurate device for the gaging of tapers.

It is evident that if two round discs of unequal diameter are placed on a surface plate a certain distance apart, two straight edges touching these two discs will represent a certain taper. It is also evident that with the measuring instruments now in use it is a simple matter to measure accurately the diameters of the two discs, and the distance these discs are apart. These three dimensions accurately and positively determine the taper represented by the straight edges touching the rolls. If a record is made of these three dimensions, these conditions can be reproduced at any time, thus making it possible to duplicate a taper piece even though the part may not at the time be accessible.

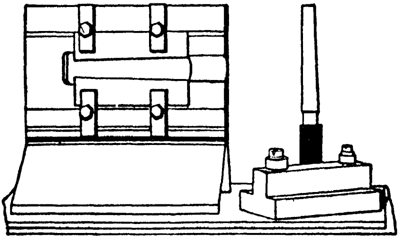

FIG. 1.—Accurate Taper Gage

The formulas on the following pages may be of service in connection with a gage of this character.

Formulas for Use in Connection with Taper Gage

To find center distance (l), refer to Fig. 2.

$$l = \frac{R - r}{t}\sqrt{1 + t^2}.$$

To find disc diameters, refer to Fig. 3.

$$= \frac{a}{L}\left[\sqrt{L^2 + (b - a)^2} + (b - a)\right].$$

Diameter of small disc = $2r$.

$$R = \frac{b}{L}\left[\sqrt{L^2 + (b - a)^2} - (b - a)\right].$$

Diameter of large disc = $2\,R$.
To find taper per foot (T), refer to Fig. 4.

$$T = 24\left(\frac{R - r}{\sqrt{l^2 - (R - r)^2}}\right).$$

To find width of opening at ends, refer to Fig. 5.

$$= r\sqrt{\frac{l - (R - r)}{l + (R - r)}}.$$

Width of opening at small end = $2\,a$.

$$b = R\sqrt{\frac{l + (R - r)}{l - (R - r)}}.$$

Width of opening at large end = $2\,b$.

Applications of Formulas

TO FIND CENTER DISTANCE BETWEEN DISCS

Suppose there are two discs, as shown in Fig. 2, whose diameters are respectively $1\frac{1}{4}$ and 1 inch. It is desired to construct a taper of $\frac{3}{4}$ to the foot, and the center distance l between discs must be determined in order that the gage jaws when touching both discs shall give that taper.

Let R = radius of large disc, or 0.625 inch.
r = radius of small disc, or 0.500 inch.
t = taper per inch on side, or

$$\frac{0.750}{24} = 0.03125 \text{ inch.}$$

Then
$$l = \frac{R - r}{t}\sqrt{1 + t^2}$$
$$= \frac{0.125}{0.03125}\sqrt{1.000976}$$
$$= 4 \times 1.0005 = 4.002 \text{ inches.}$$

TO FIND DISC DIAMETERS

Suppose the gage jaws are to be set as in Fig. 3 for a 3 inch per foot taper whose length is to be 4 inches. The small end is to be exactly $\frac{1}{2}$ inch and the large end for this taper will, therefore, be $1\frac{1}{2}$ inches. What diameter must the discs be made so that when the jaws are in contact with them and the distance L over the discs measures 4 inches, the taper will be exactly 3 inches per foot? Here a represents one-half the width of opening at the small end,

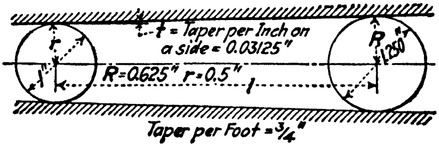

FIG. 2

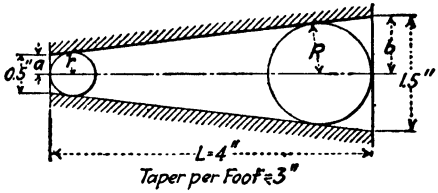

FIG. 3

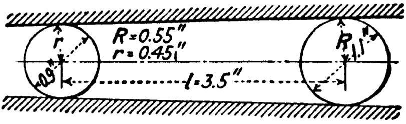

FIG. 4

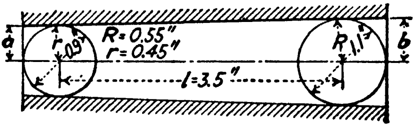

FIG. 5

FIG. 5.—Setting Taper Gage with Discs

and b one-half the width of opening at the large end. The radius of the small disc may be found by the formula:

$$r = \frac{a}{L}\left\{\sqrt{L^2 + (b-a)^2} + (b-a)\right\}.$$

Then

$$r = \frac{0.250}{4}\left(\sqrt{16 + 0.25} + 0.5\right)$$

$$= 0.0625(4.0311 + 0.5) = 0.2832.$$

Diameter of small disc = 0.2832 inch × 2 = 0.5664 inch.
For the large disc:

$$R = \frac{b}{L}\left\{\sqrt{L^2 + (b-a)^2} - (b-a)\right\}.$$

Then
$$R = \frac{0.75}{4}\left(\sqrt{16 + 0.25} - 0.5\right)$$
$$= 0.1875(4.0311 - 0.5) = 0.6621.$$

Diameter of large disc = 0.6621 inch × 2 = 1.3242 inches.

To Find Taper per Foot

In duplicating a taper, the gage jaws may be set to the model, and, by placing between the jaws a pair of discs whose diameters are known, the taper per foot may be readily found. For example, the jaws in Fig. 4 are set to a certain model, two discs 0.9 and 1.1 inch diameter are placed between them and the distance over the discs measured, from which dimension l (which is 3.5 inches) is readily found by subtracting half the diameters of the discs. Here l represents the center distance as in Fig. 2. To determine the taper per foot which may be represented by T, the formula is:

$$T = 24\left(\frac{R - r}{\sqrt{l^2 - (R - r)^2}}\right).$$

Then
$$T = 24\left(\frac{0.1}{\sqrt{12.25 - 0.01}}\right)$$
$$= 24\left(\frac{0.1}{3.4985}\right) = 0.684.$$

Taper per foot = 0.684 inch.

To Find Width of Opening at Ends

If, with the ends of the gage jaws flush with a line tangent to the disc peripheries as in Fig. 5, it is required to find the width of the opening at the small end, where a represents one-half that width, the following formula may be applied, the discs being as in the last example 0.9 and 1.1 inch diameter, respectively, and the center distance 3.5 inches:

$$a = r\sqrt{\frac{l - (R - r)}{l + (R - r)}}.$$

Then
$$a = 0.45\sqrt{\frac{3.5 - (0.55 - 0.45)}{3.5 + (0.55 - 0.45)}}$$
$$= 0.45\sqrt{\frac{3.4}{3.6}} = 0.45\sqrt{0.94444} = 0.4373.$$

0.4373 inch × 2 = 0.8746 inch, width of opening at small end of gage.

Similarly the width of opening at the large end of the gage may be found as follows, where b = half the width of the large end.

$$b = R\sqrt{\frac{l + (R - r)}{l - (R - r)}}.$$

Then

$$b = 0.55\sqrt{\frac{3.5 + (0.55 - 0.45)}{3.5 - (0.55 - 0.45)}}$$

$$= 0.55\sqrt{\frac{3.6}{3.4}}$$

$$= 0.55\sqrt{1.02899} = 0.56595.$$

0.56595 inch × 2 = 1.1319 inch = width of opening at large end.

STANDARD SELF-HOLDING (SLOW) TAPERS

Standardizing of self-holding, or "slow," tapers has been slow because of conflicting interests and the widespread use of the Morse taper. A compromise was adopted in October 1943, as seen in Table 1, which includes three sizes of Brown and Sharpe, eight sizes of Morse, and the rest of the $\frac{3}{4}$ inch to the foot taper.

A self-releasing or "fast" taper of $3\frac{1}{2}$ inches per foot, the same as now used in milling machines, has also been standardized. They are shown in Table 8.

TABLE 1.—TAPER SERIES—BASIC DIMENSIONS
(In Inches)

No. of Taper	Taper per Foot	Diameter at Gage Line[1] *A*	Means of Driving and Holding				Origin of Series
239	0.50200	0.23922	Tongue drive with shank held in by friction (see Table 2)				Brown and Sharpe taper series Nos. 1 to 3
299	0.50200	0.29968					
375	0.50200	0.37525		Tongue drive with shank held in by key (see Table 3)			
1	0.59858	0.47500					Morse taper series
2	0.59941	0.70000					
3	0.60235	0.93800					
4	0.62326	1.2310					
4½	0.62400	1.5000					
5	0.63151	1.7480					
6	0.62565	2.4940					
7	0.62400	3.2700					
200	0.75000	1.9999			Key drive with shank held in by key (see Table 4)	Key drive with shank held in by draw-bolt (see Table 5)	¾ inch per foot taper series
250	0.75000	2.4999					
300	0.75000	2.9999					
350	0.75000	3.4999					
400	0.75000	3.9999					
450	0.75000	4.4999					
500	0.75000	4.9999					
600	0.75000	5.9999					
800	0.75000	7.9999					
1000	0.75000	9.9999					
1200	0.75000	11.9999					

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[1] See illustrations with Tables 2, 3, 4 and 5.

A tolerance of 0.005 inch either way is allowed on all fractional dimensions unless otherwise noted.

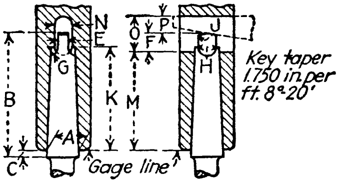
TABLE 2.—TONGUE DRIVE WITH SHANK RETAINED BY FRICTION

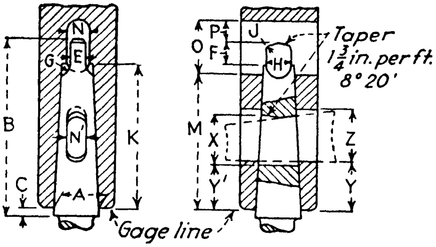
No of taper	Diameter at Gage Line[1]	Shank		Tongue					Socket	Keyway			
		Over-All Length	Ex-posed Length	Thick-ness	Length	Radius of Mill	Diam-eter	Radius	Depth	End of Socket to Key-way	Width	Length	Tongue to Bot-tom of Keyway
	A	B	C	E	F	G	H	J	K	M	N	O	P
239	0.23922	1 9/32	3/32	0.1250	3/16	3/16	11/64	1/32	1 1/16	15/16	0.141	3/8	1/8
299	0.29968	1 19/32	3/32	0.1562	1/4	3/16	7/32	1/32	1 5/16	1 11/64	0.172	1/2	11/64
375	0.37525	1 31/32	3/32	0.1875	5/16	3/16	9/32	3/64	1 5/8	1 15/32	0.203	5/8	7/32
1	0.47500	2 9/16	1/8	0.2031	3/8	3/16	11/32	3/64	2 3/16	2 1/16	0.213	3/4	3/8
2	0.70000	3 1/8	3/16	0.2500	7/16	1/4	17/32	1/16	2 5/8	2 1/2	0.260	7/8	7/16
3	0.93800	3 7/8	3/16	0.3125	9/16	9/32	23/32	5/64	3 1/4	3 1/16	0.322	1 3/16	9/16
4	1.2310	4 7/8	1/4	0.4687	5/8	5/16	31/32	3/32	4 1/8	3 7/8	0.478	1 1/4	1/2
4½	1.5000	5 3/8	1/4	0.5625	11/16	3/8	1 13/64	1/8	4 9/16	4 5/16	0.573	1 3/8	9/16
5	1.7480	6 1/8	1/4	0.6250	3/4	3/8	1 15/32	1/8	5 1/4	4 15/16	0.635	1 1/2	9/16
6	2.4940	8 9/16	5/16	0.7500	1 1/8	1/2	2	5/32	7 3/8	7	0.760	1 3/4	1/2
7	3.2700	11 5/8	3/8	1.1250	1 3/8	3/4	2 5/8	3/16	10 1/8	9 1/2	1.135	2 5/8	7/8

[1] See Table 6 for plug gage dimensions.

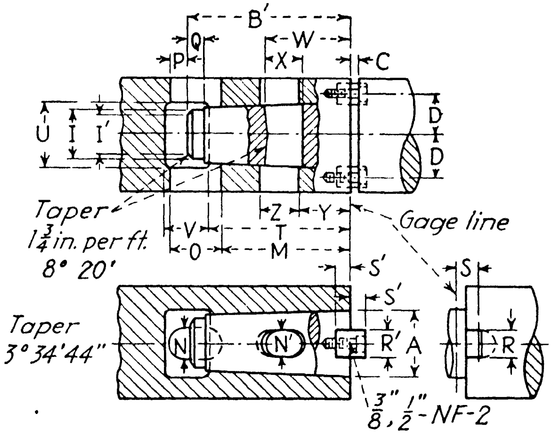
Tolerances

Diameter of shank at gage line *A*, +0.002 − 0.000.
Diameter of hole at gage line *A*, +0.000 − 0.002.
Thickness of tongue (*E*) No. 239 to No. 5 inclusive + 0.000 − 0.006; larger than No. 5, +0.000 − 0.008.
Width of keyway *N* No. 239 to No. 5 inclusive, +0.006 − 0.000; larger than No. 5, 0.008 − 0.000.
Concentricity of tongue *E* with N ℄ o. 239 to No. 5 inclusive; 0.0035; larger than No. 5, 0.007.
Concentricity of keyway *N* with ℄ No. 239 to No. 5 inclusive, −0.0035; larger than No. 5, 0.007.
Fractional dimensions ± 0.010 unless otherwise specified.
A tolerance of 0.005 inch either way is allowed on all fractional dimensions unless otherwise noted.

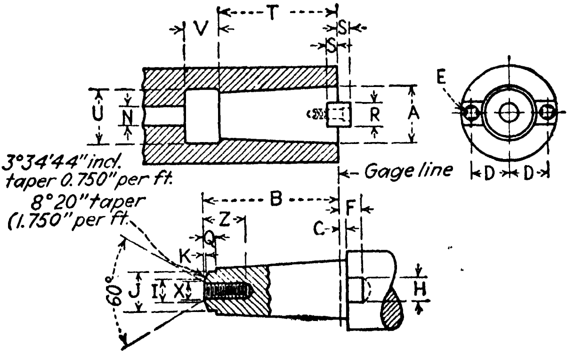




Tongue Drive with Shank Retained by Key—See Table 3


B'
Q
W
P
X
C
U
I
I'
D
D
Taper $1\frac{3}{4}$ in. per ft. 8° 20'
Z
Y
V
T
O
M
Gage line
S'
S
S'
Taper 3° 34' 44"
N
N'
R'
A
R
$\frac{3}{8}$", $\frac{1}{2}$"-NF-2

Key Drive with Shank Retained by Key—See Table 4


V
T
S
S
U
N
R
A
E
3°34'44" incl. taper 0.750" per ft.
Gage line
D
D
8°20" taper (1.750" per ft.
B
Z
F
Q
C
K
60°
J
I
X
H

Key Drive with Shank Retained by Draw Bolt—See Table 5

TABLE 3.—KEY DRIVE WITH SHANK RETAINED BY KEY
(Dimensions in Inches)

No. of Taper	Diameter at Gage Line[2]	Shank							Drive Key		Holdback Keyway in Shank[3]		
		Length from Gage Line	Exposed Length	Length of Relief	Diameter of Flat	Diameter of Relief	Drive Keyway		Center Line to Center of Screw	Fine Thread Screw (*NF*)	Gage Line to Back of Keyway	Length	Width
							Width	Depth					
	A	*B'*	*C*	*Q*	*I'*	*I*	*R*	*S*	*D*		*W*	*X*	*N'*
200	2.000	$5\frac{1}{8}$	Min. 0.003 Max. 0.067 for all Sizes	$\frac{1}{4}$	$1\frac{1}{8}$	$1\frac{5}{8}$	1.005	$\frac{9}{16}$	$1\frac{13}{32}$	$\frac{3}{8}$	$3\frac{7}{16}$	$1\frac{9}{16}$	0.656
250	2.500	$5\frac{7}{8}$		$\frac{1}{4}$	$1\frac{1}{8}$	$2\frac{1}{16}$	1.005	$\frac{9}{16}$	$1\frac{21}{32}$	$\frac{3}{8}$	$3\frac{11}{16}$	$1\frac{9}{16}$	0.781
300	3.000	$6\frac{5}{8}$		$\frac{1}{4}$	$1\frac{3}{8}$	$2\frac{1}{2}$	2.005	$\frac{9}{16}$	$2\frac{1}{4}$	$\frac{3}{8}$	$4\frac{1}{16}$	$1\frac{9}{16}$	1.031
350	3.500	$7\frac{7}{16}$		$\frac{5}{16}$	2	$2\frac{15}{16}$	2.005	$\frac{9}{16}$	$2\frac{1}{2}$	$\frac{3}{8}$	$4\frac{7}{8}$	2	1.031
400	4.000	$8\frac{3}{16}$		$\frac{5}{16}$	$2\frac{3}{8}$	$3\frac{5}{16}$	2.005	$\frac{9}{16}$	$2\frac{3}{4}$	$\frac{3}{8}$	$5\frac{5}{16}$	$2\frac{1}{4}$	1.031
450	4.500	9		$\frac{3}{8}$	$2\frac{3}{8}$	$3\frac{13}{16}$	3.005	$\frac{13}{16}$	3	$\frac{1}{2}$	$5\frac{7}{8}$	$2\frac{7}{16}$	1.031
500	5.000	$9\frac{3}{4}$		$\frac{3}{8}$	$2\frac{1}{2}$	$4\frac{1}{4}$	3.005	$\frac{13}{16}$	$3\frac{1}{4}$	$\frac{1}{2}$	$6\frac{7}{16}$	$2\frac{5}{8}$	1.031
600	6.000	$11\frac{5}{16}$		$\frac{7}{16}$	$2\frac{5}{8}$	7	3.005	$\frac{13}{16}$	$3\frac{3}{4}$	$\frac{1}{2}$	$7\frac{7}{16}$	3	1.281
800	8.000	$14\frac{3}{8}$		$\frac{1}{2}$	$3\frac{1}{2}$	$5\frac{3}{16}$	4.010	$1\frac{1}{16}$	$4\frac{3}{4}$	$\frac{1}{2}$	$9\frac{9}{16}$	4	1.781
1,000	10.000	$17\frac{7}{16}$		$\frac{5}{8}$	$4\frac{1}{2}$	$8\frac{3}{4}$	4.010	$1\frac{1}{16}$	...	..	$11\frac{1}{2}$	$4\frac{3}{4}$	2.031
1,200	12.000	$20\frac{1}{2}$		$\frac{3}{4}$	$5\frac{3}{8}$	$10\frac{1}{2}$	4.010	$1\frac{1}{16}$	...	..	$13\frac{3}{4}$	$5\frac{3}{4}$	2.531

No. of Taper	Socket						Knockout Keyway[3]			Holdback Keyway[3] in Socket		
	Drive Keyway		Gage Line to Front of Relief	Diameter Relief	Depth Relief	Gage Line to Keyway	Width	Length	Shank End to Back of Keyway	Gage Line to Front of Keyway	Length	Width
	Width	Depth										
	R′	*S′*	*T*	*U*	*V*	*M*	*N*	*O*	*P*	*Y*	*Z*	*N′*
200	1.000	$\frac{1}{2}$	$4\frac{3}{4}$	$1\frac{13}{16}$	1	$4\frac{1}{2}$	0.656	$1\frac{9}{16}$	$\frac{15}{16}$	2	$1\frac{11}{16}$	0.656
250	1.000	$\frac{1}{2}$	$5\frac{1}{2}$	$2\frac{1}{4}$	1	$5\frac{3}{16}$	0.781	$1\frac{15}{16}$	$1\frac{1}{4}$	$2\frac{1}{4}$	$1\frac{11}{16}$	0.781
300	2.000	$\frac{1}{2}$	$6\frac{1}{4}$	$2\frac{3}{4}$	1	$5\frac{15}{16}$	1.031	$2\frac{3}{16}$	$1\frac{1}{2}$	$2\frac{5}{8}$	$1\frac{11}{16}$	1.031
350	2.000	$\frac{1}{2}$	$6\frac{15}{16}$	$3\frac{3}{16}$	$1\frac{1}{4}$	$6\frac{3}{4}$	1.031	$2\frac{3}{16}$	$1\frac{1}{2}$	3	$2\frac{1}{8}$	1.031
400	2.000	$\frac{1}{2}$	$7\frac{11}{16}$	$3\frac{5}{8}$	$1\frac{1}{4}$	$7\frac{1}{2}$	1.031	$2\frac{3}{16}$	$1\frac{1}{2}$	$3\frac{1}{4}$	$2\frac{3}{8}$	1.031
450	3.000	$\frac{3}{4}$	$8\frac{3}{8}$	$4\frac{5}{16}$	$1\frac{1}{2}$	8	1.031	$2\frac{3}{4}$	$1\frac{3}{4}$	$3\frac{5}{8}$	$2\frac{9}{16}$	1.031
500	3.000	$\frac{3}{4}$	$9\frac{1}{8}$	$4\frac{5}{8}$	$1\frac{1}{2}$	$8\frac{3}{4}$	1.031	$2\frac{3}{4}$	$1\frac{3}{4}$	4	$2\frac{3}{4}$	1.031
600	3.000	$\frac{3}{4}$	$10\frac{9}{16}$	$5\frac{1}{2}$	$1\frac{3}{4}$	$10\frac{1}{8}$	1.281	$3\frac{1}{4}$	$2\frac{1}{16}$	$4\frac{5}{8}$	$3\frac{1}{4}$	1.281
800	4.000	1	$13\frac{1}{2}$	$7\frac{3}{8}$	2	$12\frac{7}{8}$	1.781	$4\frac{1}{4}$	$2\frac{3}{4}$	$5\frac{3}{4}$	$4\frac{1}{4}$	1.781
1,000	4.000	1	$16\frac{5}{16}$	$9\frac{3}{16}$	$2\frac{1}{2}$	$15\frac{3}{4}$	2.031	5	$3\frac{5}{16}$	7	5	2.031
1,200	4:000	1	19	11	3	$18\frac{1}{2}$	2.531	6	4	$8\frac{1}{4}$	6	2.531

[1] See figure on page 791.

[2] See Table 6 for plug gage dimensions.

[3] Corners at entrance side of keyways shall be chamfered at 45 degrees, as follows: Nos. 200 to 350, inclusive, $\frac{1}{16}$ inch deep; Nos. 400 to 600, inclusive, $\frac{3}{32}$ inch deep; Nos. 800 to 1200, inclusive, $\frac{1}{8}$ inch deep.

Tolerances

For Diameter of Shank at Gage Line *A*
All sizes, +0.002 − 0.000
For Diameter of Hole at Gage Line *A*
All sizes, +0.000 − 0.002
For Width of Knockout Keyway *N*
+0.008 − 0.000
For Width of Drive Keyway *R′*
In socket, +0.000 − 0.001

For Width of Drive Keyway *R*
In shank, +0.010 − 0.000
For Concentricity of Knockout Keyway *N*
With center line of spindle, 0.007
For Concentricity of Keyway *R′*
With center line of spindle, 0.002
Tolerances on Fractional Dimensions,
±0.010 unless otherwise specified.

TABLE 4.—TONGUE DRIVE WITH SHANK RETAINED BY KEY[1] (Dimensions in Inches)

No. of Taper	Diameter at Gage Line[2]	Shank		Tongue					Holdback Keyway—Shank[3]			Socket		Knockout Keyway[3]			Holdback Keyway—Socket[3]		
	A	Overall Length B	Exposed Length C	Thickness E	Length F	Radius of Mill G	Diameter H	Radius J	Gage Line to Bottom of Keyway Y'	Length X	Width N'	Depth K	Gage Line to Keyway M	Width N	Length O	Shank End to Back of Keyway P	Gage Line to Front of Keyway Y	Length Z	Width N'
3	0.93800	$3\frac{7}{8}$	$\frac{3}{16}$	$\frac{5}{16}$	$\frac{9}{16}$	$\frac{9}{32}$	$\frac{23}{32}$	$\frac{5}{64}$	$1\frac{1}{32}$	$1\frac{1}{8}$	0.260	$3\frac{1}{4}$	$3\frac{1}{16}$	0.322	$1\frac{3}{16}$	$\frac{9}{16}$	$1\frac{1}{8}$	$1\frac{3}{16}$	0.260
4	1.23100	$4\frac{7}{8}$	$\frac{1}{4}$	$\frac{15}{32}$	$\frac{5}{8}$	$\frac{5}{16}$	$\frac{31}{32}$	$\frac{3}{32}$	$1\frac{13}{32}$	$1\frac{3}{16}$	0.385	$4\frac{1}{8}$	$3\frac{7}{8}$	0.478	$1\frac{1}{4}$	$\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{4}$	0.385
$4\frac{1}{2}$	1.50000	$5\frac{3}{8}$	$\frac{1}{4}$	$\frac{9}{16}$	$\frac{11}{16}$	$\frac{3}{8}$	$1\frac{13}{64}$	$\frac{1}{8}$	$1\frac{23}{32}$	$1\frac{1}{4}$	0.447	$4\frac{9}{16}$	$4\frac{5}{16}$	0.573	$1\frac{3}{8}$	$\frac{9}{16}$	$1\frac{13}{16}$	$1\frac{3}{8}$	0.447
5	1.74800	$6\frac{1}{8}$	$\frac{1}{4}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{8}$	$1\frac{13}{32}$	$\frac{1}{8}$	2	$1\frac{3}{8}$	0.510	$5\frac{1}{4}$	$4\frac{15}{16}$	0.635	$1\frac{1}{2}$	$\frac{9}{16}$	$2\frac{1}{8}$	$1\frac{1}{4}$	0.510
6[4]	2.49100	$8\frac{9}{16}$	$\frac{5}{16}$	$\frac{3}{4}$	$1\frac{1}{8}$	$\frac{1}{2}$	2	$\frac{5}{32}$	$2\frac{1}{8}$	$1\frac{5}{8}$	0.635	$7\frac{3}{8}$	7	0.760	$1\frac{3}{4}$	$\frac{1}{2}$	$2\frac{1}{4}$	$1\frac{3}{4}$	0.635
7[4]	3.27000	$11\frac{5}{8}$	$\frac{3}{8}$	$1\frac{1}{8}$	$1\frac{3}{8}$	$\frac{3}{4}$	$2\frac{5}{8}$	$\frac{3}{16}$	$2\frac{1}{2}$	$1\frac{11}{16}$	0.760	$10\frac{1}{8}$	$9\frac{1}{2}$	1.135	$2\frac{5}{8}$	$\frac{7}{8}$	$2\frac{5}{8}$	$1\frac{13}{16}$	0.760

[1] See figure on page 791.
[2] See Table 6 for plug gage dimensions.
[3] Corners at entrance side of keyways shall be chamfered at 45 degrees as follows: No. 3, $\frac{3}{64}$ inch and all other sizes $\frac{1}{16}$ inch deep.
[4] These sizes are continued in the Tongue Drive series for the present to meet special needs.

Tolerances

For Diameter of Shank at Gage Line A
All sizes, $+0.002 - 0.000$
For Diameter of Hole at Gage Line A
All sizes, $+0.000 - 0.002$
For Thickness of Tongue E
Up to and including No. 5, $+0.000 - 0.006$
Larger than No. 5, $+0.000 - 0.008$
For Width of Knockout Keyway N
Up to and including No. 5, $+0.006 - 0.000$
Larger than No. 5, $+0.008 - 0.000$

For Concentricity of Tongue E with center line of taper
Up to and including No. 5, 0.0035 (Indicator reading)
Larger than No. 5, 0.005 (Indicator reading)
For Concentricity of Knockout Keyway N with center line of taper
Up to and including No. 5, 0.0035 (Indicator reading)
Larger than No. 5, 0.005 (Indicator reading)
Tolerances on Fractional Dimensions, ±0.010 unless otherwise specified

TABLE 5.—KEY DRIVE WITH SHANK RETAINED BY DRAW BOLT[1]
(Dimensions in Inches)

No. of Taper	Shank											Drive Key		Socket					
				Screw Thread Holdback Rod		Drive Keyway												Drive Keyway	
	Diameter at Gage Line[2] *A*	Length from Gage Line *B′*	Exposed Length *C*	Diameter (*NC*-)	Depth of Thread	Width *R*	Depth *S*	Diameter of Flat *I′*	Depth of 60 Deg. Center	Length of Relief *Q*	Diameter of Relief *I*	Center Line to Center of Screw *D*	Fine Thread Series Screw (*NF*)	Gage Line to Front of Relief *T*	Diameter Relief *U*	Depth Relief *V*	Diameter Draw Bolt Hole *d*	Width *R′*	Depth *S′*
200	2.000	5 1/8	Min. 0.003 Max 0.067 for All Sizes	7/8	1 3/4	1.005	9/16	1 1/8	1/8	1/4	1 5/8	1 13/32	3/8	4 3/4	1 13/16	1	1	1.000	1/2
250	2.500	5 7/8		7/8	1 3/4	1.005	9/16	1 1/8	1/8	1/4	2 1/16	1 21/32	3/8	5 1/2	2 1/4	1	1	1.000	1/2
300	3.000	6 5/8		1	2	2.005	9/16	1 3/8	3/16	1/4	2 1/2	2 1/4	3/8	6 1/4	2 3/4	1	1 1/8	2.000	1/2
350	3.500	7 7/16		1	2	2.005	9/16	2	3/16	5/16	2 15/16	2 1/2	3/8	6 15/16	3 3/16	1 1/4	1 1/8	2.000	1/2
400	4.000	8 3/16		1 1/4	2 1/2	2.005	9/16	2 3/8	1/4	5/16	3 5/16	2 3/4	3/8	7 11/16	3 5/8	1 1/4	1 3/8	2.000	1/2
450	4.500	9		1 1/4	2 1/2	3.005	13/16	2 3/8	1/4	3/8	3 13/16	3	1/2	8 3/8	4 3/16	1 1/2	1 3/8	3.000	3/4
500	5.000	9 3/4		1 1/4	2 1/2	3.005	13/16	2 1/2	3/8	3/8	4 1/4	3 1/4	1/2	9 1/8	4 5/8	1 1/2	1 3/8	3.000	3/4
600	6.000	11 5/16		1 1/2	3	3.005	13/16	2 5/8	3/8	7/16	5 3/16	3 3/4	1/2	10 9/16	5 1/2	1 3/4	1 5/8	3.000	3/4
800	8.000	14 3/8		1 1/2	3	4.010	1 1/16	3 1/2	1/2	1/2	7	4 3/4	1/2	13 1/2	7 3/8	2	1 5/8	4.000	1
1,000	10.000	17 7/16		2	4	4.010	1 1/16	4 1/2	1/2	5/8	8 3/4	. . .	. .	16 5/16	9 3/16	2 1/2	2 1/4	4.000	1
1,200	12.000	20 1/2		2	4	4.010	1 1/16	5 3/8	1/2	3/4	10 1/2	. . .	. .	19	11	3	2 1/4	4.000	1

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[1] See figure on page 791.

[2] See Table 6 for plug gage dimensions.

Tolerances

For Diameter of Hole at Gage Line *A*
All sizes, +0.000 − 0.002
For Diameter of Shank at Gage Line *A*
All sizes, +0.002 − 0.000
For Width of Drive Keyway *R′*
In socket, +0.000 − 0.001
For Width of Drive Keyway *R*
In shank, +0.010 − 0.000
For Concentricity of Drive Keyway *R*
With center line of spindle, 0.003
For Concentricity of Drive Keyway *R′*
With center line of spindle, 0.001
Tolerances of Fractional Dimensions,
±0.010 unless otherwise specified

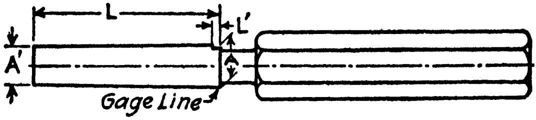


TABLE 6.—PLUG GAGES
(Dimensions in Inches)

No. of Taper	Taper[2] per Foot	Diameter[1,2] at Gage Line *A*	Diameter[1,3] at Small End *A'*	Length Gage Line to Small End *L*	Depth of Gaging Notch *L'*
.239	0.50200	0.23922	0.20000	15/16	0.048
.299	0.50200	0.29968	0.25000	1 3/16	0.048
.375	0.50200	0.37525	0.31250	1 1/2	0.048
1	0.59858	0.47500	0.36900	2 1/8	0.040
2	0.59941	0.70000	0.57200	2 9/16	0.040
3	0.60235	0.93800	0.77800	3 3/16	0.040
4	0.62326	1.23100	1.02000	4 1/16	0.038
4½	0.62400	1.50000	1.26600	4 1/2	0.038
5	0.63151	1.74800	1.47500	5 3/16	0.038
6[4]	0.62565	2.49400	2.11600	7 1/4	0.038
7[4]	0.62400	3.27000	2.75000	10	0.038
200	0.750	2.000	1.703	4 3/4	0.032
250	0.750	2.500	2.156	5 1/2	0.032
300	0.750	3.000	2.609	6 1/4	0.032
350	0.750	3.500	3.063	7	0.032
400	0.750	4.000	3.516	7 3/4	0.032
450	0.750	4.500	3.969	8 1/2	0.032
500	0.750	5.000	4.422	9 1/4	0.032
600	0.750	6.000	5.328	10 3/4	0.032
800	0.750	8.000	7.141	13 3/4	0.032
1,000	0.750	10.000	8.953	16 3/4	0.032
1,200	0.750	12.000	10.766	19 3/4	0.032

---

[1] Gage tolerance for diameters *A* and *A'*
Sizes .239 to No. 3, inclusive, +0.0001 − 0.0000.
Sizes No. 4 to No. 300, inclusive, +0.00015 − 0.0000.
Sizes No. 350 to No. 1200, inclusive, +0.0002 − 0.0000.

[2] Taper per foor and diameter at gage line basic dimensions.

[3] Dimension calculated for reference only.

[4] These sizes are continued in the Tongue Drive series for the present to meet special needs.

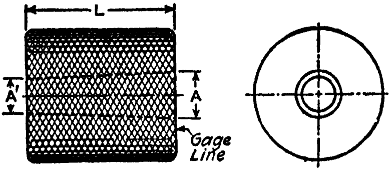


TABLE 7.—RING GAGE
(Dimensions in Inches)

No. of Taper	Taper per Foot[2]	Diameter at Gage Line[1,2] A	Diameter at Small End[1,3] A'	Length L
.239	0.50200	0.23922	0.20000	$\frac{15}{16}$
.299	0.50200	0.29968	0.25000	1$\frac{3}{16}$
.375	0.50200	0.37525	0.31250	1$\frac{1}{2}$
1	0.59858	0.47500	0.36900	2$\frac{1}{8}$
2	0.59941	0.70000	0.57200	2$\frac{9}{16}$
3	0.60235	0.93800	0.77800	3$\frac{3}{16}$
4	0.62326	1.23100	1.02000	4$\frac{1}{16}$
4$\frac{1}{2}$	0.62400	1.50000	1.26600	4$\frac{1}{2}$
5	0.63151	1.74800	1.47500	5$\frac{3}{16}$
6[4]	0.62565	2.49400	2.11600	7$\frac{1}{4}$
7[4]	0.62400	3.2700	2.75000	10
200	0.750	2.0000	1.703	4$\frac{3}{4}$
250	0.750	2.5000	2.156	5$\frac{1}{2}$
300	01750	3.0000	2.609	6$\frac{1}{4}$
350	0.750	3.5000	3.063	7
400	0.750	4.0000	3.516	7$\frac{3}{4}$
450	0.750	4.500	3.969	8$\frac{1}{2}$
500	0.750	5.0000	4.422	9$\frac{1}{4}$
600	0.750	6.0000	5.328	10$\frac{3}{4}$
800	0.750	8.0000	7.141	13$\frac{3}{4}$
1,000	0.750	10.0000	8.953	16$\frac{3}{4}$
1,200	0.750	12.0000	10.766	19$\frac{3}{4}$

[1] Gage tolerance for diameters *A* and *A'*
Sizes to No. 3 inclusive, −0.0001 + 0.0000.
Sizes No. 4 to No. 300 inclusive, − 0.00015 + 0.0000.
Sizes No. 350 to 1200 inclusive, −0.0002 + 0.0000.

[2] Taper per foot and diameter at gage line basic dimensions.

[3] Dimensions calculated for reference only.

[4] These sizes are continued in the Tongue Drive series for the present to meet special needs.

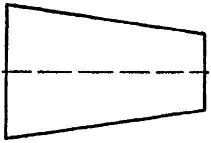
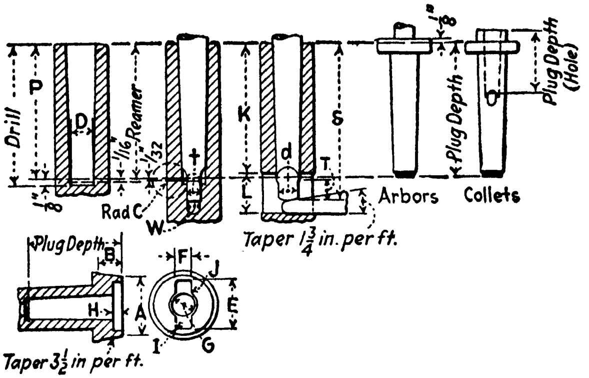


TABLE 8.—DIMENSIONS OF STEEP MACHINE TAPERS
(Dimensions in Inches)

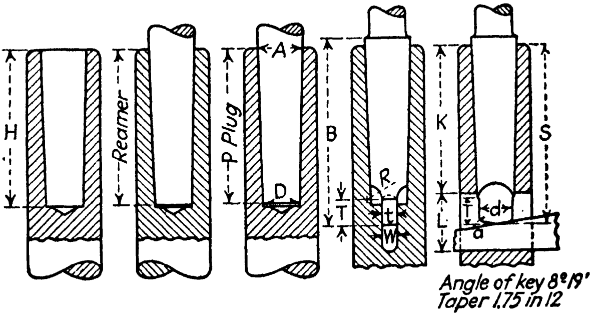
No. of Taper	Taper per Foot[1]	Diameter at Gage Line		Length along Axis	
5	3.500	1/2	0.500	11/16	0.6875
10	3.500	5/8	0.625	7/8	0.8750
15	3.500	3/4	0.750	1 1/16	1.0625
20	3.500	7/8	0.875	1 5/16	1.3125
25	3.500	1	1.000	1 9/16	1.5625
30	3.500	1 1/4	1.250	1 7/8	1.8750
35	3.500	1 1/2	1.500	2 1/4	2.2500
40	3.500	1 3/4	1.750	2 11/16	2.6875
45	3.500	2 1/4	2.250	3 5/16	3.3125
50	3.500	2 3/4	2.750	4	4.0000
55	3.500	3 1/2	3.500	5 3/16	5.1875
60	3.500	4 1/4	4.250	6 3/8	6.3750

[1] This taper corresponds to an included angle of 16 degrees, 35 minutes, 33.4 seconds.

The tapers numbered 10, 20, 30, 40, 50, and 60 are designated "Preferred Series." The tapers numbered 5, 15, 25, 35, 45, and 55 are designated "Intermediate Series."



Dimensions of Brown & Sharpe Tapers



Dimensions of Morse Tapers

The majority of American tool builders formerly used the Brown and Sharpe taper in their milling-machine spindles, and the Morse taper in their lathes and drilling machines. Practically all milling machines are now made with A.S.A. taper and nearly all lathes use the new standard spindle nose. Both the Sellers taper, which had a key in addition to the taper fit, and the "Jarno" taper of 0.6 inch per foot have been abandoned.

Brown & Sharpe Tapers—Taper ½-inch per Foot Except No. 10, Which is 0.5161-inch per Foot
(Dimensions in Inches)

No. of Taper	Diam. of Plug at Small End D	Plug Depth P: B. & S.* Standard	Plug Depth P: Milling-Mach. Standard	Plug Depth P: Miscellaneous	Keyway from End of Spindle K	Shank Depth S	Length of Keyway† L	Width of Keyway W	Length of Arbor Tongue T	Diameter of Arbor Tongue d	Thickness of Arbor Tongue t	Radius of Tongue Circle c	Radius of Tongue at a a	Limit for Tongue to Project through Test Tool
1	0.200	15/16			15/16	1 3/16	3/8	0.135	3/16	0.170	1/8	3/16	0.030	0.003
2	0.250	1 3/16			1 11/64	1 1/2	1/2	0.166	1/4	0.220	5/32	3/16	0.030	0.003
		1 1/2			1 15/32	1 7/8	5/8	0.197	5/16	0.282	3/16	3/16	0.040	0.003
3	0.312			1 3/4	1 23/32	2 1/8	5/8	0.197	5/16	0.282	3/16	3/16	0.040	0.003
				2	1 31/32	2 3/8	5/8	0.197	5/16	0.282	3/16	3/16	0.040	0.003
4	0.350		1 1/4		1 13/64	1 21/32	11/16	0.228	11/32	0.320	7/32	5/16	0.050	0.003
		1 11/16			1 41/64	2 3/32	11/16	0.228	11/32	0.320	7/32	5/16	0.050	0.003
			1 3/4		1 11/16	2 3/16	3/4	0.260	3/8	0.420	1/4	5/16	0.060	0.003
5	0.450			2	1 15/16	2 7/16	3/4	0.260	3/8	0.420	1/4	5/16	0.060	0.003
		2 1/8			2 1/16	2 9/16	3/4	0.260	3/8	0.420	1/4	5/16	0.060	0.003
6	0.500	2 3/8			2 17/64	2 7/8	7/8	0.291	7/16	0.460	9/32	5/16	0.060	0.005
				2 1/2	2 11/32	3 1/32	15/16	0.322	15/32	0.560	5/16	3/8	0.070	0.005
7	0.600	2 7/8			2 25/32	3 13/32	15/16	0.322	15/32	0.560	5/16	3/8	0.070	0.005
			3		2 29/32	3 17/32	15/16	0.322	15/32	0.560	5/16	3/8	0.070	0.005
8	0.750	3 9/16			3 11/64	4 1/8	1	0.353	1/2	0.710	11/32	3/8	0.080	0.005

9	0.900		4		3 7/8	4 5/8	1 1/8	0.385	9/16	0.860	3/8	7/16	0.100	0.005
		4 1/4			4 1/8	4 7/8	1 1/8	0.385	9/16	0.860	3/8	7/16	0.100	0.005
		5			4 21/32	5 23/32	1 5/16	0.447	21/32	1.010	7/16	7/16	0.110	0.005
10	1.0446		5 11/16		5 17/32	6 13/32	1 5/16	0.447	21/32	1.010	7/16	7/16	0.110	0.005
				6 7/32	6 1/16	6 15/16	1 5/16	0.447	21/32	1.010	7/16	7/16	0.110	0.005
11	1.250	5 15/16			5 25/32	6 21/32	1 5/16	0.447	21/32	1.210	7/16	1/2	0.130	0.005
			6 3/4		6 19/32	7 15/32	1 5/16	0.447	21/32	1.210	7/16	1/2	0.130	0.005
12	1.500	7 1/8	7 1/8	6 1/4	6 15/16	7 15/16	1 1/2	0.510	3/4	1.460	1/2	1/2	0.150	0.005
13	1.750	7 3/4			7 9/16	8 9/16	1 1/2	0.510	3/4	1.710	1/2	5/8	0.170	0.010
14	2.00	8 1/4	8 1/4		8 1/32	9 5/32	1 11/16	0.572	27/32	1.960	9/16	3/4	0.190	0.010
15	2.25	8 3/4			8 17/32	9 21/32	1 11/16	0.572	27/32	2.210	9/16	7/8	0.210	0.010
16	2.50	9 1/4			9	10 1/4	1 7/8	0.635	15/16	2.450	5/8	1	0.230	0.010
17	2.75	9 3/4												
18	3.00	10 1/4												

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* "B & S Standard" plug depths are not used in all cases.

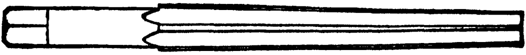
† Special lengths of keyway are used instead of standard lengths in some places. Standard lengths need not be used when keyway is for driving only and not for admitting key to force out tool.

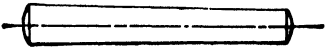
MORSE TAPERS

Number of Taper	Diameter of Plug at Small End D	Diameter at End of Socket A	Shank		Depth of Hole H	Standard Plug Depth P	Tongue					Keyway		End of Socket to Keyway K	Taper per Inch	Taper per Foot	No. of Key
			Whole Length B	Depth S			Thickness t	Length T	Radius R	Diameter d	Radius a	Width W	Length L				
0	0.252	0.3561	2 11/32	2 11/32	2 1/32	2	0.1562	1/4	5/32	0.235	0.04	0.160	9/16	1 15/16	0.052050	0.62460	0
1	0.369	0.475	2 9/16	2 7/16	2 3/16	2 1/8	0.2031	3/8	3/16	0.343	0.05	0.213	3/4	2 1/16	0.049882	0.59858	1
2	0.572	0.700	3 1/8	2 15/16	2 5/8	2 9/16	0.250	7/16	1/4	17/32	0.06	0.260	7/8	2 1/2	0.049951	0.59941	2
3	0.778	0.938	3 7/8	3 11/16	3 1/4	3 3/16	0.3125	9/16	9/32	23/32	0.08	0.322	1 3/16	3 1/16	0.050196	0.60235	3
4	1.020	1.231	4 7/8	4 5/8	4 1/8	4 1/16	0.4687	5/8	5/16	31/32	0.10	0.478	1 1/4	3 7/8	0.051938	0.62326	4
4½	1.2660	1.500	5 3/8	5 1/8	4 9/16	4 1/2	0.5625	11/16	3/8	1 13/64	0.12	0.573	1 3/8	4 5/16	0.0520	0.6240	
5	1.475	1.748	6 1/8	5 7/8	5 1/4	5 3/16	0.6250	3/4	3/8	1 13/32	0.12	0.635	1 1/2	4 15/16	0.052626	0.63151	5
6	2.116	2.494	8 9/16	8 1/4	7 3/8	7 1/4	0.750	1 1/8	1/2	2	0.15	0.760	1 3/4	7	0.052137	0.62565	6
7	2.750	3.270	11 5/8	11 1/4	10 1/8	10	1.1250	1 3/8	3/4	2 5/8	0.18	1.135	2 5/8	9 1/2	0.05200	0.6240	7

$\frac{A - D}{P}$ = taper per inch (to 7 places).

TAPER PINS AND REAMERS





TAPER REAMERS AND PINS[1]
Taper = 1/4 Inch per Foot or 0.0208 Inch per Inch

Size. No.	Dia. of Small End of Reamer	Dia. of Large End of Reamer	Length of Flute	Total Length of Reamer	Size Drill for Reamer	Longest Limit Length of Pin	Dia. of Large End of Pin	Approx. Fractional Size at Large End of Pin
0	0.135″	.162″	1 5/16″	2″	28	1″	.156″	5/32″
1	.146″	.179″	1 9/16″	2 3/8″	25	1 1/4″	.172″	11/64″
2	.162″	.200″	1 13/16″	2 11/16″	19	1 1/2″	.193″	3/16″
3	.183″	.226″	2 1/16″	3″	12	1 3/4″	.219″	7/32″
4	.208″	.257″	2 3/8″	3 7/16″	3	2″	.250″	1/4″
5	.240″	.300″	2 7/8″	4 1/8″	1/4	2 1/4	.289″	19/64″
6	.279″	.354″	3 5/8″	5″	9/32	3 1/4″	.341″	11/32″
7	.331″	.423″	4 7/16″	6 1/16″	11/32	3 3/4″	.409″	13/32″
8	.398″	.507″	5 1/4″	7 1/16	13/32	4 1/2″	.492″	1/2″
9	.482″	.609″	6 1/8″	8 1/8″	31/64	5 1/4″	.591″	19/32″
10	.581″	.727″	7″	9 1/2″	19/32	6″	.706″	23/32″
11	.706″	.878″	8 1/4″	11 1/4″	23/32	7 1/4″	.857″	55/64″
12	.842″	1.050″	10″	13 3/8″	55/64	8 3/4″	1.013″	1 1/64″
13	1.009″	1.259″	12″	16″	1 1/64	10 3/4″	1.233″	1 15/64″

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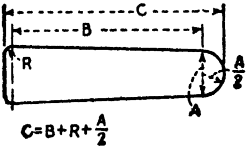
[1] Pratt & Whitney Co.

These reamer sizes are so proportioned that each overlaps the size smaller about 1/2 inch.



Brown & Sharpe Mfg. Co.'s Taper Pins
(Tool Steel, Taper 1/4-Inch per Foot) (Dimensions in Inches)

No. of pin	00	0	1	2	3	4
Diam. at small end *A*	0.118	0.135	0.146	0.162	0.183	0.208
Approx. diam. small end	1/8	9/64	9/64	5/32	3/16	7/32
Diam. of shaft	9/32–5/16	3/8–7/16	1/2–9/16	5/8–11/16	3/4–13/16	7/8–15/16
Radius of corner *R*	0.01	0.01	0.01	0.02	0.02	0.02

No. of pin	5	6	7	8	9	10
Diam. at small end *A*	0.240	0.279	0.331	0.398	0.482	0.581
Approx. diam. small end	1/4	9/32	11/32	13/32	15/32	19/32
Diam. of shaft	1–1 1/8	1 3/16–1 5/16	1 3/8–1 1/2	1 9/16–11/16	1 3/4–1 7/8	1 15/16–2 1/16
Radius of corner *R*	0.02	0.03	0.03	0.04	0.04	0.05

The flat head and rounded point remove all doubt as to which is the large end of the pin. Lengths vary by 1/8-inch increments for general use.

Taper of Cock Plugs

While there is no standard taper for cock plugs, a taper of 1 1/8 inches per foot is used in many cases.

To Select Taper Pins for Shaft[1]

The accompanying table gives shaft diameters on which the various sizes of pins may be used. In the first table the size of pin shown for a given shaft diameter will prove satisfactory for all ordinary applications.

Lengths listed in the left-hand column of the second table are given for standard-size pins. These pins are usually obtainable from stock. All sizes listed above the heavy line are of suitable length for use with standard length reamers. By referring to the diameter at the small end of the pin, the drill size for any pin can be obtained.

If the table at the top of the chart is used as a guide in specifying the size of taper pin, the same size pin will be used consistently for a given shaft diameter. The maximum length indicated for standard reamers is a guide in selecting hub diameters.

M. G. Demougeot.

STANDARD TAPER PINS USED BY THE U. S. ORDNANCE DEPARTMENT

The accompanying tables show the standard taper and split pin used by the Ordnance Department of the U. S. Army as revised up to July 20, 1912. The first table shows the standard taper pins and the retaining split pins used in the end. The pins are ¼-inch taper per foot. They have tapered head and point to allow for upsetting, either in driving or removing pins from the work.

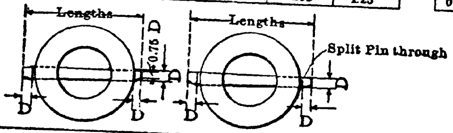
The first table gives the number of the pin and the diameter at the small end in the first two columns. The next three columns show the sizes of the shaft and collars in which these pins are used, while the last two columns show the split pins which are used in some cases on the small end of the taper pin to prevent accidental withdrawal from the hole.

The second table shows the dimensions of the standard split pin used in connection with the taper pins, and gives the diameter and the length manufactured. The tapered points are shown by the drawing to be the length of the diameter of the split pin, with the small end of the taper 0.75 of the diameter.

STANDARD TAPER PINS and Retaining Split Pins

0.25 per Ft. Taper

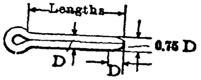
TAPER PINS		WORK			SPLIT PINS	
DIA. AT SMALL END		USED IN SHAFTS		COLLARS	DIAM.	LENGTH
Number	D	Min. Diam.	Max. Diam.	Max. Diam.		
	0.0625		0.3	0.75		
	0.09375	0.3	0.5	1		
0	0.135	0.5	0.75	1.125	0.0468	0.3125
2	0.162	0.75	1	1.625	0.0625	0.375
4	0.208	1	1.5	2.125	0.0781	0.4375
6	0.279	1.5	2	3.25	0.09375	0.5
8	0.398	2	3	4.875	0.125	0.75
10	0.581	3	4.5	6.625	0.156	1
12	0.842	4.5	6.5	9.625	0.203	1.25



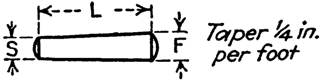
STANDARD SPLIT PINS

DIAM.	LENGTHS MANUFACTURED														
0.0468	0.3125	0.5													
0.0625	0.375	0.5625	0.75												
0.0781	0.4375	0.625	0.8125	1											
0.09375	0.5	0.75	1	1.25	1.5	1.75	2	ALL PINS BELOW THIS LINE							
0.125	0.5	0.75	1	1.25	1.5	1.75	2	ARE COMMERCIAL SIZES							
0.156	0.5	0 75	1	1.25	1.5	1.75	2	2.25	2.5						
0.203		0 75	1	1.25	1.5	1.75	2	2.25	2.5						
0.25			1	1.25	1.5	1.75	2	2.25	2.5	2.75	3				
0.375			1	1.25	1.5	1.75	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
0.5	Also	5 and 6 inch			1.5	1.75	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
0.625	Also	5 and 6 incn					2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
											3	3.25	3.5	3.75	4

D = Nominal Diam. or Diam. of Hole to Receive Pin



TAPER PINS



Diameter at Large End *F* for Various Shaft Diameters

No. of Pin	$\frac{7}{0}$	$\frac{6}{0}$	$\frac{5}{0}$	$\frac{4}{0}$	$\frac{3}{0}$	$\frac{2}{0}$	$\frac{1}{0}$	1	2	3	4	5	6	7	8	9	10
Shaft diameter to be used on under average conditions	$\frac{3}{16}$	$\frac{7}{32}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$ and $\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	1	1$\frac{1}{4}$	1$\frac{1}{2}$	2	2$\frac{1}{2}$
F-diameter at large end	0.062	0.0715	0.092	0.108	0.125	0.141	0.156	0.172	0.193	0.219	0.250	0.289	0.341	0.409	0.492	0.591	0.706
Approximate fractional size	$\frac{1}{16}$	$\frac{5}{64}$	$\frac{3}{32}$	$\frac{7}{64}$	$\frac{1}{8}$	$\frac{9}{64}$	$\frac{5}{32}$	$\frac{11}{64}$	$\frac{3}{16}$	$\frac{7}{32}$	$\frac{1}{4}$	$\frac{19}{64}$	$\frac{11}{32}$	$\frac{13}{32}$	$\frac{1}{2}$	$\frac{19}{32}$	$\frac{23}{32}$

Diameter at Small End *S* for Various Lengths

L-length of Pin	Taper Pin Number										
	$\frac{1}{0}$	1	2	3	4	5	6	7	8	9	10
$\frac{3}{4}$	0.140	0.156	0.177	0.203	0.235						
1	0.135	0.151	0.172	0.198	0.230	0.268					

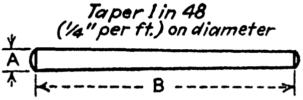
1¼	0.130	0.146	0.167	0.192	0.224	0.263	0.315				
1½	0.125	0.141	0.162	0.187	0.219	0.258	0.310				
1¾		0.136	0.157	0.182	0.214	0.252	0.305				
2		0.130	0.151	0.177	0.209	0.247	0.299	0.367	0.450		
2¼			0.146	0.172	0.204	0.242	0.294	0.362	0.445		
2½			0.141	0.166	0.198	0.237	0.289	0.356	0.440		
2¾				0.161	0.193	0.232	0.284	0.351	0.434	0.534	
3				0.156	0.188	0.227	0.279	0.346	0.429	0.528	
3¼							0.273	0.340	0.424	0.523	
3½							0.268	0.335	0.419	0.518	0.633
3¾							0.263	0.330	0.414	0.513	0.628
4							0.258	0.326	0.409	0.508	0.623
4¼									0.403	0.502	0.617
4½									0.398	0.497	0.612
4¾									0.393	0.492	0.607
5									0 389	0.487	0.602
5¼										0.482	0.597
5½										0.476	0.591
5¾										0.471	0.586
6										0.466	0.581

TAPERS FROM 1/16 TO 1 1/4 INCH PER FOOT

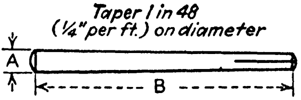
AMOUNT OF TAPER FOR LENGTHS UP TO 24 INCHES

Length of Tapered Portion	Taper per Foot									
	1/16	3/32	1/8	1/4	3/8	1/2	5/8	3/4	1	1 1/4
1/32	.0002	.0002	.0003	.0007	.0010	.0013	.0016	.0020	.0026	.0033
1/16	.0003	.0005	.0007	.0013	.0020	.0026	.0033	.0039	.0052	.0065
1/8	.0007	.0010	.0013	.0026	.0039	.0052	.0065	.0078	.0104	.0130
3/16	.0010	.0015	.0020	.0039	.0059	.0078	.0098	.0117	.0156	.0195
1/4	.0013	.0020	.0026	.0052	.0078	.0104	.0130	.0156	.0208	.0260
5/16	.0016	.0024	.0033	.0065	.0098	.0130	.0163	.0195	.0260	.0326
3/8	.0020	.0029	.0039	.0078	.0117	.0156	.0195	.0234	.0312	.0391
7/16	.0023	.0034	.0046	.0091	.0137	.0182	.0228	.0273	.0365	.0456
1/2	.0026	.0039	.0052	.0104	.0156	.0208	.0260	.0312	.0417	.0521
9/16	.0029	.0044	.0059	.0117	.0176	.0234	.0293	.0352	.0469	.0586
5/8	.0033	.0049	.0065	.0130	.0195	.0260	.0326	.0391	.0521	.0651
11/16	.0036	.0054	.0072	.0143	.0215	.0286	.0358	.0430	.0573	.0716
3/4	.0039	.0059	.0078	.0156	.0234	.0312	.0391	.0469	.0625	.0781
13/16	.0042	.0063	.0085	.0169	.0254	.0339	.0423	.0508	.0677	.0846
7/8	.0046	.0068	.0091	.0182	.0273	.0365	.0456	.0547	.0729	.0911
15/16	.0049	.0073	.0098	.0195	.0293	.0391	.0488	.0586	.0781	.0977
1	.0052	.0078	.0104	.0208	.0312	.0417	.0521	.0625	.0833	.1042
2	.0104	.0156	.0208	.0417	.0625	.0833	.1042	.125	.1667	.2083
3	.0156	.0234	.0312	.0625	.0937	.1250	.1562	.1875	.250	.3125
4	.0208	.0312	.0417	.0833	.125	.1667	.2083	.250	.3333	.4167
5	.0260	.0391	.0521	.1042	.1562	.2083	.2604	.3125	.4167	.5208
6	.0312	.0469	.0625	.125	.1875	.250	.3125	.375	.500	.625
7	.0365	.0547	.0729	.1458	.2187	.2917	.3646	.4375	.5833	.7292
8	.0417	.0625	.0833	.1667	.250	.3333	.4167	.500	.6667	.8333
9	.0469	.0703	.0937	.1875	.2812	.375	.4687	.5625	.750	.9375
10	.0521	.0781	.1042	.2083	.3125	.4167	.5208	.625	.8333	1.0417
11	.0573	.0859	.1146	.2292	.3437	.4583	.5729	.6875	.9167	1.1458
12	.0625	.0937	.125	.250	.375	.500	.625	.750	1.000	1.250
13	.0677	.1016	.1354	.2708	.4062	.5417	.6771	.8125	1.0833	1.3542
14	.0729	.1094	.1458	.2917	.4375	.5833	.7292	.875	1.1667	1.4583
15	.0781	.1172	.1562	.3125	.4687	.625	.7812	.9375	1.250	1.5625
16	.0833	.125	.1667	.3333	.500	.6667	.8333	1.000	1.3333	1.6667
17	.0885	.1328	.1771	.3542	.5312	.7083	.8854	1.0625	1.4167	1.7708
18	.0937	.1406	.1875	.3750	.5625	.750	.9375	1.125	1.500	1.875
19	.0990	.1484	.1979	.3958	.5937	.7917	.9896	1.1875	1.5833	1.9792
20	.1042	.1562	.2083	.4167	.625	.8333	1.0417	1.250	1.6667	2.0833
21	.1094	.1641	.2187	.4375	.6562	.875	1.0937	1.3125	1.750	2.1875
22	.1146	.1719	.2292	.4583	.6875	.9167	1.1458	1.375	1.8333	2.2917
23	.1198	.1797	.2396	.4792	.7187	.9583	1.1979	1.4375	1.9167	2.3958
24	.125	.1875	.250	.500	.750	1.000	1.250	1.500	2.000	2.500

Solid and Split Taper Pins
British Standard
(January, 1935)



Solid Taper Pin



Split Taper Pin

All sizes shown ○ and ⦶ in this Table are standard for Solid Taper Pins.

Only those sizes shown ⦶ are standard for Split Taper Pins.

Diameter at Large End A ±0.002 inch	Length B (in inches)																	
	1/2	3/4	1	1 1/4	1 1/2	1 3/4	2	2 1/4	2 1/2	2 3/4	3	3 1/4	3 1/2	4	4 1/2	5	5 1/2	6
1/16	○	○	○	○	○													
5/64	○	○	○	○	○													
3/32	○	⦶	⦶	○	○	○	○											
7/64	○	○	○	○	○	○	○											
1/8	○	⦶	⦶	⦶	⦶	⦶	⦶											
5/32	○	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶									
3/16		⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶				
7/32			⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶			
1/4			⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶		
9/32				○	○	○	○	○	○	○	○	○	○	○	○	○	○	
5/16				⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶
11/32					○	○	○	○	○	○	○	○	○	○	○	○	○	○
3/8					⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶
7/16							○	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶
1/2									○	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶
9/16										○	○	○	⦶	⦶	⦶	⦶	⦶	⦶
5/8													○	⦶	⦶	⦶	⦶	⦶

Split taper pins shall be split at their small end for a length of not less than 20 per cent of the length of the pin. The pins shall be split and not sawn.

TAPERS PER FOOT IN INCHES AND CORRESPONDING ANGLES

Taper per Foot	Included Angle			Angle with Center Line			Taper per Foot	Included Angle			Angle with Center Line		
	Deg.	Min.	Sec	Deg.	Min.	Sec.		Deg.	Min.	Sec.	Deg.	Min.	Sec.
1/64	0	4	28	0	2	14	1	4	46	18	2	23	9
1/32	0	8	58	0	4	29	1 1/8	5	22	40	2	41	50
1/16	0	17	53	0	8	57	1 1/4	5	57	48	2	58	54
3/32	0	26	52	0	13	26	1 3/8	6	33	26	3	16	43
1/8	0	35	48	0	17	54	1 1/2	7	9	10	3	34	35
5/32	0	44	44	0	22	22	1 5/8	7	44	48	3	52	24
3/16	0	53	44	0	26	52	1 3/4	8	20	26	4	10	13
7/32	1	2	36	0	31	18	1 7/8	8	56	2	4	28	1
1/4	1	11	36	0	35	48	2	9	31	36	4	45	48
9/32	1	20	30	0	40	15	2 1/4	10	42	42	5	21	21
5/16	1	29	30	0	44	45	2 1/2	11	53	36	5	56	48
11/32	1	38	26	0	49	13	2 3/4	13	4	24	6	32	12
3/8	1	47	24	0	53	42	3	14	15	0	7	7	30
13/32	1	56	24	0	58	12	3 1/4	15	25	24	7	42	42
7/16	2	5	18	1	2	39	3 1/2	16	35	40	8	17	50
15/32	2	14	16	1	7	8	3 3/4	17	45	40	8	52	50
1/2	2	23	10	1	11	35	4	18	55	24	9	27	42
17/32	2	32	4	1	16	2	4 1/4	20	5	2	10	2	31
9/16	2	41	4	1	20	32	4 1/2	21	14	20	10	37	10
19/32	2	50	2	1	25	1	4 3/4	22	23	22	11	11	41
5/8	2	59	0	1	29	30	5	23	32	12	11	46	6
21/32	3	7	56	1	33	58	5 1/4	24	40	42	12	20	21
11/16	3	16	54	1	38	27	5 1/2	25	48	48	12	54	24
23/32	3	25	50	1	42	55	5 3/4	26	56	46	13	28	23
3/4	3	34	44	1	47	21	6	28	4	20	14	2	10
25/32	3	43	44	1	51	52	6 1/4	29	11	34	14	35	47
13/16	3	52	38	1	56	19	6 1/2	30	18	26	15	9	13
27/32	4	1	32	2	0	46	6 3/4	31	25	2	15	42	31
7/8	4	10	32	2	5	16	7	32	31	12	16	15	36
29/32	4	19	26	2	9	43	7 1/4	33	37	44	16	48	32
15/16	4	28	24	2	14	12	7 1/2	34	42	30	17	21	15
31/32	4	37	20	2	18	40	8	35	47	32	17	53	46
							8 1/2	36	52	12	18	26	6

TABLE FOR USE IN COMPUTING TAPERS

In the table on pages 810 and 811, the quantities when expressed in inches represent the taper per inch corresponding to various angles advancing by 10 minutes from 10 minutes to 90 degrees. If an angle is given as, say, 27½ degrees and it is desired to find the corresponding taper in inches, the amount, 0.4894, may be taken directly from the table. This is the taper per inch of length measured as in Fig. 6, along the axis. The taper in inches per foot of length is found by multiplying the tabulated quantity by 12, and in this particular case it would be 0.4894 inch × 12 = 5.8728 inches. Where the included angle is not found directly in the table, the taper

per inch is found as follows: Assume that the angle in question is 12¼ degrees, then the nearest angles in the table are 12 degrees 10 minutes and 12 degrees 20 minutes, the respective quantities tabulated under these angles being 0.21314 and 0.21610. The difference between the two is 0.00296, and as 12¼ degrees is half way between 12 degrees 10 minutes and 12 degrees 20 minutes one-half of 0.00296, or 0.00148 is added to 0.21314, giving 0.21462 inch as the taper of a piece 1 inch in length and of an included angle of 12¼ degrees. The taper per foot equals 0.21462 inch × 12 = 2.5754 inches.

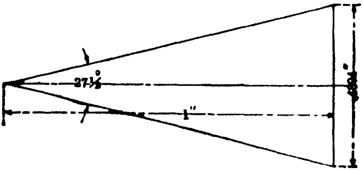


FIG. 6.—Taper per Inch and Corresponding Angle

TABLE FOR DIMENSIONING DOVETAIL SLIDES AND GIBS

The table on page 812 is figured for machine-tool work so as to enable one to tell at a glance the amount to be added or subtracted in dimensioning dovetail slides and their gibs for the usual angles up to 60 degrees. The column for 45-degree dovetails is omitted, as *A* and *B* would, of course, be alike for this angle.

In the application of the table, assuming a base with even dimensions, as in the sketch in Fig. 7, to obtain the dimensions *x* and *y* of the slide, Fig. 8, allowing for the gib which may be assumed to be ¼ inch thick, the perpendicular depth of the dovetail being ⅝ inch, and the angle 60 degrees, look under column *A* for ⅝ inch, and it will be found opposite this that *B* is 0.360 inch, which subtracted from 2 inches gives 1.640 inches, the dimension *x*. To find *y* first get the dimension 1.640 inches, then under the column for 60-degree gibs (where *C* is ¼ inch), *D* is found to be 0.289 inch, which is added to 1.640, giving 1.929 inches.

In practice, this dimension is usually made a little larger, say to the nearest 64th, to allow for fitting the gib.

MEASURING EXTERNAL AND INTERNAL DOVETAILS

The accompanying table of constants is for use with the plug method of sizing dovetail gages, etc. The constants are calculated for the plugs and angles most in use; and to use them a knowledge of arithmetic is all that is required. The formulas by which they were obtained are added for the convenience of those who may have an unusual angle to make.

As an example of the use of the table, suppose that *Z*, Fig. 9, is the dimension wanted, and that the dimension *A* and the angle *a* are

TABLE FOR COMPUTING TAPERS

The Tabulated Quantities = Twice the Tangent of Half the Angle.

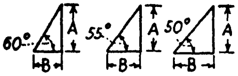
Deg.	0′	10′	20′	30′	40′	50′	60′
0	.00000	.00290	.00582	.00872	.01164	.01454	.01746
1	.01746	.02036	.02326	.02618	.02910	.03200	.03492
2	.03492	.03782	.04072	.04364	.04656	.04946	.05238
3	.05238	.05528	.05820	.06110	.06402	.06692	.06984
4	.06984	.07276	.07566	.07858	.08150	.08440	.08732
5	.08732	.09024	.09316	.09606	.09898	.10190	.10482
6	.10482	.10774	.11066	.11356	.11648	.11940	.12232
7	.12232	.12524	.12816	.13108	.13400	.13694	.13986
8	.13986	.14278	.14570	.14862	.15156	.15448	.15740
9	.15740	.16034	.16326	.16618	.16912	.17204	.17498
10	.17498	.17790	.18084	.18378	.18670	.18964	.19258
11	.19258	.19552	.19846	.20138	.20432	.20726	.21020
12	.21020	.21314	.21610	.21904	.22198	.22492	.22788
13	.22788	.23082	.23376	.23672	.23966	.24262	.24556
14	.24556	.24852	.25148	.25444	.25738	.26034	.26330
15	.26330	.26626	.26922	.27218	.27516	.27812	.28108
16	.28108	.28404	.28702	.28998	.29296	.29592	.29890
17	.29890	.30188	.30486	.30782	.31080	.31378	.31676
18	.31676	.31976	.32274	.32572	.32870	.33170	.33468
19	.33468	.33768	.34066	.34366	.34666	.34966	.35266
20	.35266	.35566	.35866	.36166	.36466	.36768	.37068
21	.37068	.37368	.37670	.37972	.38272	.38574	.38876
22	.38876	.39178	.39480	.39782	.40084	.40388	.40690
23	.40690	.40994	.41296	.41600	.41904	.42208	.42512
24	.42512	.42816	.43120	.43424	.43728	.44034	.44338
25	.44338	.44644	.44950	.45256	.45562	.45868	.46174
26	.46174	.46480	.46786	.47094	.47400	.47708	.48016
27	.48016	.48324	.48632	.48940	.49248	.49556	.49866
28	.49866	.50174	.50484	.50794	.51004	.51414	.51724
29	.51724	.52034	.52344	.52656	.52966	.53278	.53590
30	.53590	.53902	.54214	.54526	.54838	.55152	.55464
31	.55464	.55778	.56092	.56406	.56720	.57034	.57350
32	.57350	.57664	.57980	.58294	.58610	.58926	.59242
33	.59242	.59560	.59876	.60194	.60510	.60828	.61146
34	.61146	.61464	.61782	.62102	.62420	.62740	.63060
35	.63060	.63380	.63700	.64020	.64342	.64662	.64984
36	.64984	.65306	.65628	.65950	.66272	.66596	.66920
37	.66920	.67242	.67566	.67890	.68216	.68540	.68866
38	.68866	.69192	.69516	.69844	.70170	.70496	.70824
39	.70824	.71152	.71480	.71808	.72136	.72464	.72794
40	.72794	.73124	.73454	.73784	.74114	.74446	.74776
41	.74776	.75108	.75440	.75774	.76106	.76440	.76772
42	.76772	.77106	.77442	.77776	.78110	.78446	.78782
43	.78782	.79118	.79454	.79792	.80130	.80468	.80806
44	.80806	.81144	.81482	.81822	.82162	.82502	.82842
45	.82842	.83184	.83526	.83866	.84210	.84552	.84894

TABLE FOR COMPUTING TAPERS

The Tabulated Quantities = Twice the Tangent of Half the Angle.

Deg.	0′	10′	20′	30′	40′	50′	60′
46	.84894	.85238	.85582	.85926	.86272	.86616	.86962
47	.86962	.87308	.87656	.88002	.88350	.88698	.89046
48	.89046	.89394	.89744	.90094	.90444	.90794	.91146
49	.91146	.91496	.91848	.92202	.92554	.92908	.93262
50	.93262	.93616	.93970	.94326	.94682	.95038	.95396
51	.95396	.95752	.96110	.96468	.96828	.97186	.97546
52	.97546	.97906	.98268	.98630	.98990	.99354	.99716
53	.99716	1.00080	1.00444	1.00808	1.01174	1.01538	1.01906
54	1.01906	1.02272	1.02638	1.03006	1.03376	1.03744	1.04114
55	1.04114	1.04484	1.04854	1.05226	1.05596	1.05970	1.06342
56	1.06342	1.06716	1.07090	1.07464	1.07840	1.08214	1.08592
57	1.08592	1.08968	1.09346	1.09724	1.10102	1.10482	1.10862
58	1.10862	1.11242	1.11624	1.12006	1.12388	1.12770	1.13154
59	1.13154	1.13538	1.13924	1.14310	1.14696	1.15082	1.15470
60	1.15470	1.15858	1.16248	1.16636	1.17026	1.17418	1.17810
61	1.17810	1.18202	1.18594	1.18988	1.19382	1.19776	1.20172
62	1.20172	1.20568	1.20966	1.21362	1.21762	1.22160	1.22560
63	1.22560	1.22960	1.23362	1.23764	1.24166	1.24570	1.24974
64	1.24974	1.25378	1.25784	1.26190	1.26598	1.27006	1.27414
65	1.27414	1.27824	1.28234	1.28644	1.29056	1.29468	1.29882
66	1.29882	1.30296	1.30710	1.31126	1.31542	1.31960	1.32378
67	1.32378	1.32796	1.33216	1.33636	1.34056	1.34478	1.34902
68	1.34902	1.35326	1.35750	1.36176	1.36602	1.37028	1.37456
69	1.37456	1.37984	1.38314	1.38744	1.39176	1.39608	1.40042
70	1.40042	1.40476	1.40910	1.41346	1.41782	1.42220	1.42658
71	1.42658	1.43098	1.43538	1.43980	1.44422	1.44864	1.45308
72	1.45308	1.45754	1.46200	1.46646	1.47094	1.47542	1.47992
73	1.47992	1.48442	1.48894	1.49348	1.49800	1.50256	1.50710
74	1.50710	1.51168	1.51624	1.52084	1.52544	1.53004	1.53466
75	1.53466	1.53928	1.54392	1.54856	1.55322	1.55790	1.56258
76	1.56258	1.56726	1.57196	1.57668	1.58140	1.58612	1.59088
77	1.59088	1.59562	1.60040	1.60516	1.60996	1.61476	1.61966
78	1.61956	1.62440	1.62922	1.63406	1.63892	1.64380	1.64868
79	1.64868	1.65356	1.65846	1.66338	1.66830	1.67324	1.67820
80	1.67820	1.68316	1.68814	1.69312	1.69812	1.70314	1.70816
81	1.70816	1.71320	1.71824	1.72332	1.72836	1.73348	1.73858
82	1.73858	1.74368	1.74882	1.75396	1.75910	1.76428	1.76946
83	1.76946	1.77464	1.77984	1.78506	1.79030	1.79554	1.80080
84	1.80080	1.80608	1.81138	1.81668	1.82198	1.82732	1.83266
85	1.83266	1.83802	1.84340	1.84878	1.85418	1.85960	1.86504
86	1.86504	1.87048	1.87594	1.88142	1.88690	1.89240	1.89792
87	1.89792	1.90346	1.90902	1.91458	1.92016	1.92576	1.93138
88	1.93138	1.93700	1.94266	1.94832	1.95400	1.95968	1.96540
89	1.96540	1.97112	1.97686	1.98262	1.98840	1.99420	2.00000
90	2.						

Refer to page 808 for explanation of table.



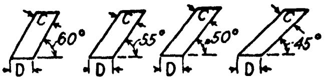


Table for Dimensioning Dovetail Slides and Gibs

A	B	B	B	C	D	D	D	D
1/32″	.018″	.022″	.027″	1/8″	.144″	.152″	.163″	.176″
1/16″	.036″	.044″	.053″	3/16″	.216″	.228″	.244″	.264″
1/8″	.072″	.087″	.105″	1/4″	.289″	.305″	.326″	.353″
1/4″	.144″	.175″	.210″	5/16″	.361″	.381″	.407″	.442″
3/8″	.216″	.262″	.314″	3/8″	.433″	.457″	.489″	.530″
1/2″	.288″	.350″	.420″	1/2″	.577″	.610″	.652″	.707″
5/8″	.360″	.437″	.525″	5/8″	.721″	.762″	.815″	.883″
3/4″	.433″	.525″	.629″	3/4″	.866″	.915″	.979″	1.060″
7/8″	.505″	.612″	.734″	7/8″	1.010″	1.067″	1.142″	1.237″
1″	.577″	.700″	.839″	1″	1.154″	1.220″	1.305″	1.414″
1 1/8″	.649″	.787″	.944″					
1 1/4″	.721″	.875″	1.049″					
1 3/8″	.794″	.962″	1.153″					
1 1/2″	.866″	1.050″	1.259″					
1 3/4″	1.010″	1.225″	1.469″					
2″	1.154″	1.400″	1.677″					
2 1/4″	1.298″	1.575″	1.888″					
2 1/2″	1.442″	1.750″	2.097″					
2 3/4″	1.588″	1.925″	2.307″					
3″	1.732″	2.100″	2.517″					
3 1/2″	2.020″	2.450″	2.937″					
4″	2.308″	2.800″	3.356″					
4 1/2″	2.598″	3.150″	3.776″					
5″	2.885″	3.501″	4.195″					

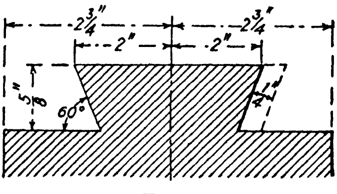


Fig. 7

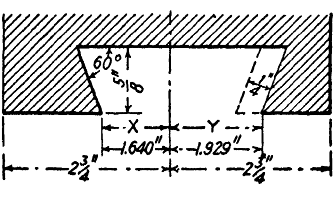


Fig. 8
Dimensioning Slides and Gibs

known. A glance at the formulas below shows that $Z = A - D$. Then the constant D corresponding to the size of plug and the angle used is subtracted from A and the remainder equals Z. For instance, if $A = 4$ inches, the plug used = $\frac{3}{8}$ inch, and the angle = 30 degrees, then $Z = A - D = 4$ inches − 1.0245 inches = 2.9755 inches.

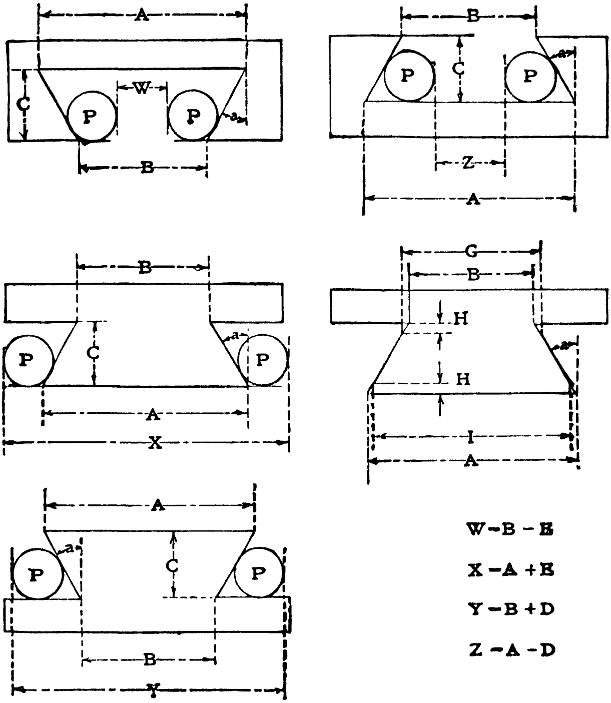


FIG. 9.—External and Internal Dovetails

If A is not known, but B and C are given, as in the formula below the table (page 814), $A = B + CF$. Then if $B = 3.134$ inches, $C = \frac{3}{4}$ inch, and the angle is 30 degrees, as before; $A = B + CF$ = 3.134 inches + (0.75 inch × 1.1547) = 4 inches, whence Z can be found, as already shown.

If the corners of the dovetail are flat, as shown in Fig. 9 at I and G, and the dimensions I and H and the angles are known, it will be found from the formulas below the table that A also $= I + HF$; so that, if $I = 3.8557$ inches, $H = \frac{1}{8}$ inch, and the angle = 30 degrees; then $A = I + HF$ = 3.8557 inches + (0.125 inch × 1.1547) = 4 inches, from which Z is found as before.

Constants for Dovetails

Plug		60°	55°	50°	45°	40°	35°	30°
¼″	D	1.1830	1.0429	.9368	.8535	.7861	.7302	.6830
	E	.3170	.3288	.3410	.3536	.3666	.3802	.3943
⅜″	D	1.7745	1.5643	1.4053	1.2803	1.1792	1.0954	1.0245
	E	.4755	.4932	.5115	.5303	.5499	.5702	.5915
½″	D	2.3660	2.0858	1.8730	1.7070	1.5722	1.4604	1.3660
	E	.6340	.6576	.6820	.7072	.7332	.7603	.7886
¾″	D	3.5490	3.1286	2.8106	2.5606	2.3584	2.1903	2.0490
	E	.9510	.9864	1.0230	1.0606	1.0998	1.1404	1.1830
	F	3.4641	2.8563	2.3836	2	1.6782	1.4004	1.1547

$$A = B + CF = I + HF$$
$$B = A - CF = G - HF$$
$$E = P\left(\cot \frac{90 + a}{2}\right) + P$$
$$D = P\left(\cot \frac{90 - a}{2}\right) + P$$
$$F = 2 \tan a$$

TOOL FOR LAYING OUT ANGLES ACCURATELY

The bevel gage in Fig. 10 is for laying out angles accurately. In using this gage, set a vernier caliper or large "micrometer" to twice the sine of half the angle desired, multiplied by 10, add ½ inch, and open the gage till it fits the vernier. This gives the angle within the limits of the measuring tool and the radius of the gage. The ⅛-inch hole in the center is for a setting plug when it is desirable to lay out an angle from a given center.

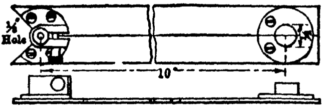


Fig. 10.—Bevel Gage for Laying Out

The table gives the measurements over the half discs required for setting the arms of the gage to give any angle from 1 to 45 degrees, and also the setting for any number of holes in a circle from 3 to 22.

Table for Setting Tool for Laying Out Angles

Gage Setting for Even Degrees

Angle Degrees	Measurement Over Disks	Angle Degrees	Measurement Over Disks	Angle Degrees	Measurement Over Disks	Angle Degrees	Measurement Over Disks
1	0.6746	12	2.5906	23	4.4874	34	6.3474
2	0.8490	13	2.764	24	4.6582	35	6.5142
3	1.0236	14	2.9374	25	4.8288	36	6.6804
4	1.1980	15	3.1106	26	4.9980	37	6.846
5	1.3724	16	3.2834	27	5.1690	38	7.0114
6	1.5468	17	3.4562	28	5.3384	39	7.1762
7	1.7210	18	3.6286	29	5.5176	40	7.3404
8	1.8952	19	3.8010	30	5.6764	41	7.5042
9	2.0692	20	3.9730	31	5.8448	42	7.6674
10	2.2432	21	4.1448	32	6.0128	43	7.830
11	2.4170	22	4.3162	33	6.1804	44	7.9922
						45	8.1536

Gage Settings for Holes in a Circle

No. of Holes in Circle	Measurement Over Disks	No. of Holes in Circle	Measurement Over Disks	No. of Holes in Circle	Measurement Over Disks	No. of Holes in Circle	Measurement Over Disks
3	17.8206	8	8.1536	13	5.2864	18	3.9730
4	14.6422	9	7.3404	14	4.9504	19	3.7918
5	12.2558	10	6.6802	15	4.6582	20	3.6286
6	10.5	11	6.1346	16	4.4018	21	3.4808
7	9.1776	12	5.6762	17	4.1750	22	3.3462

THE SINE BAR

The sine bar is an instrument of precision used by the toolmaker in laying out, setting, testing, and otherwise dealing with angular work which requires a close degree of accuracy in its dimensions. It consists of a bar of steel with two discs of equal diameter secured near the ends of the bar and having their centers on a line exactly parallel with the edge of the sine bar. The bar itself may be either tool steel hardened and ground or machine steel case hardened.

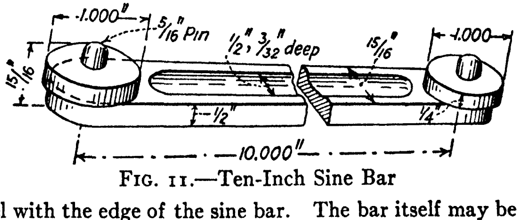


Fig. 11.—Ten-Inch Sine Bar

An improved form of sine bar is shown in Fig. 11. There are various other designs, all having for their object a convenient means

SINE BAR TABLE

Min.	Constant, 0 Deg.	Constant, 1 Deg.	Constant, 2 Deg.	Constant, 3 Deg.	Constant, 4 Deg.	Constant, 5 Deg.	Constant, 6 Deg.	Constant, 7 Deg.	Constant, 8 Deg.
0	.0000	.1745	.3490	.5234	.6976	.8716	1.0453	1.2187	1.3917
1	.0029	.1774	.3519	.5263	.7005	.8745	1.0482	1.2216	1.3946
2	.0058	.1803	.3548	.5292	.7034	.8774	1.0511	1.2245	1.3975
3	.0087	.1832	.3577	.5321	.7063	.8803	1.0540	1.2274	1.4004
4	.0116	.1862	.3606	.5350	.7092	.8831	1.0569	1.2302	1.4033
5	.0145	.1891	.3635	.5379	.7121	.8860	1.0597	1.2331	1.4061
6	.0175	.1920	.3664	.5408	.7150	.8889	1.0626	1.2360	1.4090
7	.0204	.1949	.3693	.5437	.7179	.8918	1.0655	1.2389	1.4119
8	.0233	.1978	.3723	.5466	.7208	.8947	1.0684	1.2418	1.4148
9	.0262	.2007	.3752	.5495	.7237	.8976	1.0713	1.2447	1.4177
10	.0291	.2036	.3781	.5524	.7266	.9005	1.0742	1.2476	1.4205
11	.0320	.2065	.3810	.5553	.7295	.9034	1.0771	1.2504	1.4234
12	.0349	.2094	.3839	.5582	.7324	.9063	1.0800	1.2533	1.4263
13	.0378	.2123	.3868	.5611	.7353	.9092	1.0829	1.2562	1.4292
14	.0407	.2152	.3897	.5640	.7382	.9121	1.0858	1.2591	1.4320
15	.0436	.2181	.3926	.5669	.7411	.9150	1.0887	1.2620	1.4349
16	.0465	.2211	.3955	.5698	.7440	.9179	1.0916	1.2649	1.4378
17	.0495	.2240	.3984	.5727	.7469	.9208	1.0945	1.2678	1.4407
18	.0524	.2269	.4013	.5756	.7498	.9237	1.0973	1.2706	1.4436
19	.0553	.2298	.4042	.5785	.7527	.9266	1.1002	1.2735	1.4464
20	.0582	.2327	.4071	.5814	.7556	.9295	1.1031	1.2764	1.4493
21	.0611	.2356	.4100	.5844	.7585	.9324	1.1060	1.2793	1.4522
22	.0640	.2385	.4129	.5873	.7614	.9353	1.1089	1.2822	1.4551
23	.0669	.2414	.4159	.5902	.7643	.9382	1.1118	1.2851	1.4580
24	.0698	.2443	.4188	.5931	.7672	.9411	1.1147	1.2880	1.4608
25	.0727	.2472	.4217	.5960	.7701	.9440	1.1176	1.2908	1.4637
26	.0756	.2501	.4246	.5989	.7730	.9469	1.1205	1.2937	1.4666
27	.0785	.2530	.4275	.6018	.7739	.9498	1.1234	1.2966	1.4695
28	.0814	.2560	.4304	.6047	.7788	.9527	1.1269	1.2995	1.4723
29	.0844	.2589	.4333	.6076	.7817	.9556	1.1291	1.3024	1.4752
30	.0873	.2618	.4362	.6105	.7846	.9585	1.1320	1.3053	1.4781

31	.0902	.2647	.4391	.6134	.7875	.9614	1.1349	1.3081	1.4810
32	.0931	.2676	.4420	.6163	.7904	.9642	1.1378	1.3110	1.4838
33	.0960	.2705	.4449	.6192	.7933	.9671	1.1407	1.3139	1.4867
34	.0989	.2734	.4478	.6221	.7962	.9700	1.1436	1.3168	1.4896
35	.1018	.2763	.4507	.6250	.7993	.9729	1.1465	1.3197	1.4925
36	.1047	.2792	.4536	.6279	.8020	.9758	1.1494	1.3226	1.4954
37	.1076	.2821	.4565	.6308	.8049	.9787	1.1523	1.3254	1.4982
38	.1105	.2850	.4594	.6337	.8078	.9816	1.1552	1.3283	1.5011
39	.1134	.2879	.4623	.6360	.8107	.9845	1.1580	1.3312	1.5040
40	.1164	.2908	.4653	.6395	.8136	.9874	1.1609	1.3341	1.5069
41	.1193	.2938	.4682	.6424	.8165	.9903	1.1638	1.3370	1.5097
42	.1222	.2967	.4711	.6453	.8194	.9932	1.1667	1.3399	1.5126
43	.1251	.2996	.4740	.6482	.8223	.9961	1.1696	1.3427	1.5155
44	.1280	.3025	.4769	.6511	.8252	.9990	1.1725	1.3456	1.5184
45	.1309	.3054	.4798	.6540	.8281	1.0019	1.1754	1.3485	1.5212
46	.1338	.3083	.4827	.6569	.8310	1.0048	1.1783	1.3514	1.5241
47	.1367	.3112	.4856	.6598	.8339	1.0077	1.1812	1.3543	1.5270
48	.1396	.3141	.4885	.6627	.8368	1.0106	1.1840	1.3572	1.5299
49	.1425	.3170	.4914	.6656	.8397	1.0135	1.1869	1.3600	1.5327
50	.1454	.3199	.4943	.6685	.8426	1.0164	1.1898	1.3629	1.5356
51	.1483	.3228	.4972	.6714	.8455	1.0192	1.1927	1.3658	1.5385
52	.1513	.3257	.5001	.6743	.8484	1.0221	1.1956	1.3687	1.5414
53	.1542	.3286	.5030	.6773	.8513	1.0250	1.1985	1.3716	1.5442
54	.1571	.3316	.5059	.6802	.8542	1.0279	1.2014	1.3744	1.5471
55	.1600	.3345	.5088	.6831	.8571	1.0308	1.2043	1.3773	1.5500
56	.1629	.3374	.5117	.6860	.8600	1.0337	1.2071	1.3802	1.5529
57	.1658	.3403	.5146	.6889	.8629	1.0366	1.2100	1.3831	1.5557
58	.1687	.3432	.5175	.6918	.8658	1.0395	1.2129	1.3860	1.5586
59	.1716	.3461	.5205	.6947	.8687	1.0424	1.2158	1.3889	1.5615
60	.1745	.3490	.5234	.6976	.8716	1.0453	1.2187	1.3917	1.5643

SINE BAR TABLE—*Continued*

Min.	Constant, 9 Deg.	Constant, 10 Deg.	Constant, 11 Deg.	Constant, 12 Deg.	Constant, 13 Deg.	Constant, 14 Deg.	Constant, 15 Deg.	Constant, 16 Deg.	Constant, 17 Deg.
0	1.5643	1.7365	1.9081	2.0791	2.2495	2.4192	2.5882	2.7564	2.9237
1	1.5672	1.7393	1.9109	2.0820	2.2523	2.4220	2.5910	2.7592	2.9265
2	1.5701	1.7422	1.9138	2.0848	2.2552	2.4249	2.5938	2.7620	2.9293
3	1.5730	1.7451	1.9167	2.0877	2.2580	2.4277	2.5966	2.7648	2.9321
4	1.5758	1.7479	1.9195	2.0905	2.2608	2.4305	2.5994	2.7676	2.9348
5	1.5787	1.7508	1.9224	2.0933	2.2637	2.4333	2.6022	2.7704	2.9376
6	1.5816	1.7537	1.9252	2.0962	2.2665	2.4362	2.6050	2.7731	2.9404
7	1.5845	1.7565	1.9281	2.0990	2.2693	2.4390	2.6079	2.7759	2.9432
8	1.5873	1.7594	1.9309	2.1019	2.2722	2.4418	2.6107	2.7787	2.9460
9	1.5902	1.7623	1.9338	2.1047	2.2750	2.4446	2.6135	2.7815	2.9487
10	1.5931	1.7651	1.9366	2.1076	2.2778	2.4474	2.6163	2.7843	2.9515
11	1.5959	1.7680	1.9395	2.1104	2.2807	2.4503	2.6191	2.7871	2.9543
12	1.5988	1.7708	1.9423	2.1132	2.2835	2.4531	2.6219	2.7899	2.9571
13	1.6017	1.7737	1.9452	2.1161	2.2863	2.4559	2.6247	2.7927	2.9599
14	1.6046	1.7766	1.9481	2.1189	2.2892	2.4587	2.6275	2.7955	2.9626
15	1.6074	1.7794	1.9509	2.1218	2.2920	2.4615	2.6303	2.7983	2.9654
16	1.6100	1.7823	1.9538	2.1246	2.2948	2.4644	2.6331	2.8011	2.9682
17	1.6132	1.7852	1.9566	2.1275	2.2977	2.4672	2.6359	2.8039	2.9710
18	1.6160	1.7880	1.9595	2.1303	2.3005	2.4700	2.6387	2.8067	2.9737
19	1.6189	1.7909	1.9623	2.1331	2.3033	2.4728	2.6415	2.8095	2.9765
20	1.6218	1.7937	1.9652	2.1360	2.3062	2.4756	2.6443	2.8123	2.9793
21	1.6246	1.7966	1.9680	2.1388	2.3090	2.4784	2.6471	2.8150	2.9821
22	1.6275	1.7995	1.9709	2.1417	2.3118	2.4813	2.6500	2.8178	2.9849
23	1.6304	1.8023	1.9737	2.1445	2.3146	2.4841	2.6528	2.8206	2.9876
24	1.6333	1.8052	1.9760	2.1474	2.3175	2.4869	2.6556	2.8234	2.9904
25	1.6361	1.8081	1.9794	2.1502	2.3203	2.4897	2.6584	2.8262	2.9932
26	1.6390	1.8109	1.9823	2.1530	2.3231	2.4925	2.6612	2.8290	2.9960
27	1.6419	1.8138	1.9831	2.1559	2.3260	2.4954	2.6640	2.8318	2.9987
28	1.6447	1.8166	1.9880	2.1587	2.3288	2.4982	2.6668	2.8346	3.0015
29	1.6476	1.8195	1.9908	2.1616	2.3316	2.5010	2.6696	2.8374	3.0043
30	1.6505	1.8224	1.9937	2.1644	2.3345	2.5038	2.6724	2.8402	3.0071

31	1.6533	1.8252	1.9965	2.1672	2.3373	2.5066	2.6752	2.8429	3.0098
32	1.6562	1.8281	1.9994	2.1701	2.3401	2.5094	2.6780	2.8457	3.0126
33	1.6591	1.8309	2.0022	2.1729	2.3429	2.5122	2.6808	2.8485	3.0154
34	1.6620	1.8338	2.0031	2.1758	2.3458	2.5151	2.6836	2.8513	3.0182
35	1.6648	1.8367	2.0079	2.1786	2.3486	2.5179	2.6864	2.8541	3.0209
36	1.6677	1.8395	2.0108	2.1814	2.3514	2.5207	2.6892	2.8569	3.0237
37	1.6706	1.8424	2.0136	2.1843	2.3542	2.5235	2.6920	2.8597	3.0265
38	1.6734	1.8452	2.0165	2.1871	2.3571	2.5263	2.6948	2.8625	3.0292
39	1.6763	1.8481	2.0193	2.1899	2.3599	2.5291	2.6976	2.8652	3.0320
40	1.6792	1.8509	2.0222	2.1928	2.3627	2.5320	2.7004	2.8680	3.0348
41	1.6820	1.8538	2.0250	2.1956	2.3656	2.5348	2.7032	2.8708	3.0376
42	1.6849	1.8567	2.0279	2.1985	2.3684	2.5376	2.7060	2.8736	3.0403
43	1.6878	1.8595	2.0307	2.2013	2.3712	2.5404	2.7088	2.8764	3.0431
44	1.6906	1.8624	2.0336	2.2041	2.3740	2.5432	2.7116	2.8792	3.0459
45	1.6935	1.8652	2.0364	2.2070	2.3769	2.5460	2.7144	2.8820	3.0486
46	1.6964	1.8681	2.0393	2.2098	2.3797	2.5488	2.7172	2.8847	3.0514
47	1.6992	1.8710	2.0421	2.2126	2.3825	2.5516	2.7200	2.8875	3.0542
48	1.7021	1.8738	2.0450	2.2155	2.3853	2.5545	2.7228	2.8903	3.0570
49	1.7050	1.8767	2.0478	2.2183	2.3882	2.5573	2.7256	2.8931	3.0597
50	1.7078	1.8795	2.0507	2.2212	2.3910	2.5601	2.7284	2.8959	3.0625
51	1.7107	1.8824	2.0535	2.2240	2.3938	2.5629	2.7312	2.8987	3.0653
52	1.7136	1.8852	2.0563	2.2268	2.3966	2.5657	2.7340	2.9015	3.0680
53	1.7164	1.8881	2.0592	2.2297	2.3995	2.5685	2.7368	2.9042	3.0708
54	1.7193	1.8910	2.0620	2.2325	2.4023	2.5713	2.7396	2.9070	3.0736
55	1.7222	1.8938	2.0649	2.2353	2.4051	2.5741	2.7424	2.9098	3.0763
56	1.7250	1.8967	2.0677	2.2382	2.4073	2.5769	2.7452	2.9126	3.0791
57	1.7279	1.8995	2.0706	2.2410	2.4128	2.5798	2.7480	2.9154	3.0819
58	1.7308	1.9024	2.0734	2.2438	2.4136	2.5826	2.7508	2.9182	3.0846
59	1.7336	1.9052	2.0763	2.2467	2.4164	2.5854	2.7536	2.9209	3.0874
60	1.7365	1.9081	2.0791	2.2495	2.4192	2.5882	2.7564	2.9237	3.0902

SINE BAR TABLE—*Continued*

Min.	Constant, 18 Deg.	Constant, 19 Deg.	Constant, 20 Deg.	Constant, 21 Deg.	Constant, 22 Deg.	Constant, 23 Deg.	Constant, 24 Deg.	Constant, 25 Deg.	Constant, 26 Deg.
0	3.0902	3.2557	3.4202	3.5837	3.7461	3.9073	4.0674	4.2262	4.3837
1	3.0929	3.2584	3.4229	3.5864	3.7488	3.9100	4.0700	4.2288	4.3863
2	3.0957	3.2612	3.4257	3.5891	3.7515	3.9127	4.0727	4.2315	4.3889
3	3.0986	3.2639	3.4284	3.5918	3.7542	3.9153	4.0753	4.2341	4.3916
4	3.1012	3.2667	3.4311	3.5945	3.7569	3.9180	4.0780	4.2367	4.3942
5	3.1040	3.2694	3.4339	3.5973	3.7595	3.9207	4.0806	4.2394	4.3968
6	3.1068	3.2722	3.4366	3.6000	3.7622	3.9234	4.0833	4.2420	4.3994
7	3.1095	3.2749	3.4393	3.6027	3.7649	3.9260	4.0860	4.2446	4.4020
8	3.1123	3.2777	3.4421	3.6054	3.7676	3.9287	4.0886	4.2473	4.4046
9	3.1151	3.2804	3.4448	3.6081	3.7703	3.9314	4.0913	4.2499	4.4072
10	3.1178	3.2832	3.4475	3.6108	3.7730	3.9341	4.0939	4.2525	4.4098
11	3.1206	3.2859	3.4503	3.6135	3.7757	3.9367	4.0966	4.2552	4.4124
12	3.1233	3.2887	3.4530	3.6162	3.7784	3.9394	4.0992	4.2578	4.4151
13	3.1261	3.2914	3.4557	3.6190	3.7811	3.9421	4.1019	4.2604	4.4177
14	3.1289	3.2942	3.4584	3.6217	3.7838	3.9448	4.1045	4.2631	4.4203
15	3.1316	3.2969	3.4612	3.6244	3.7865	3.9474	4.1072	4.2657	4.4229
16	3.1344	3.2997	3.4639	3.6271	3.7892	3.9501	4.1098	4.2683	4.4255
17	3.1372	3.3024	3.4666	3.6298	3.7919	3.9528	4.1125	4.2709	4.4281
18	3.1399	3.3051	3.4694	3.6325	3.7946	3.9555	4.1151	4.2736	4.4307
19	3.1427	3.3079	3.4721	3.6352	3.7973	3.9581	4.1178	4.2762	4.4333
20	3.1454	3.3106	3.4748	3.6379	3.7999	3.9608	4.1204	4.2788	4.4359
21	3.1482	3.3134	3.4775	3.6406	3.8026	3.9635	4.1231	4.2815	4.4385
22	3.1510	3.3161	3.4803	3.6434	3.8053	3.9661	4.1257	4.2841	4.4411
23	3.1537	3.3189	3.4830	3.6461	3.8080	3.9688	4.1284	4.2867	4.4437
24	3.1565	3.3216	3.4857	3.6488	3.8107	3.9715	4.1310	4.2894	4.4464
25	3.1593	3.3244	3.4884	3.6515	3.8134	3.9741	4.1337	4.2920	4.4490
26	3.1620	3.3271	3.4912	3.6542	3.8161	3.9768	4.1363	4.2946	4.4516
27	3.1648	3.3298	3.4939	3.6569	3.8188	3.9795	4.1390	4.2972	4.4542
28	3.1675	3.3326	3.4966	3.6586	3.8215	3.9822	4.1416	4.2999	4.4568
29	3.1703	3.3353	3.4993	3.6623	3.8241	3.9848	4.1443	4.3025	4.4594
30	3.1730	3.3381	3.5021	3.6650	3.8268	3.9875	4.1469	4.3051	4.4620

31	3.1758	3.3408	3.5048	3.6677	3.8295	3.9902	4.1496	4.3077	4.4646
32	3.1786	3.3436	3.5075	3.6704	3.8322	3.9928	4.1522	4.3104	4.4672
33	3.1813	3.3463	3.5102	3.6731	3.8349	3.9955	4.1549	4.3130	4.4698
34	3.1841	3.3490	3.5130	3.6758	3.8376	3.9982	4.1575	4.3156	4.4724
35	3.1868	3.3518	3.5157	3.6785	3.8403	4.0008	4.1602	4.3182	4.4750
36	3.1896	3.3545	3.5184	3.6812	3.8430	4.0035	4.1628	4.3209	4.4776
37	3.1923	3.3573	3.5211	3.6839	3.8456	4.0062	4.1655	4.3235	4.4802
38	3.1951	3.3600	3.5239	3.6867	3.8483	4.0088	4.1681	4.3261	4.4828
39	3.1979	3.3627	3.5266	3.6894	3.8510	4.0115	4.1707	4.3287	4.4854
40	3.2006	3.3655	3.5293	3.6921	3.8537	4.0141	4.1734	4.3313	4.4880
41	3.2034	3.3682	3.5320	3.6948	3.8564	4.0168	4.1760	4.3340	4.4906
42	3.2061	3.3710	3.5347	3.6975	3.8591	4.0195	4.1787	4.3366	4.4932
43	3.2089	3.3737	3.5375	3.7002	3.8617	4.0221	4.1813	4.3392	4.4958
44	3.2116	3.3764	3.5402	3.7029	3.8644	4.0248	4.1840	4.3418	4.4984
45	3.2144	3.3792	3.5429	3.7056	3.8671	4.0275	4.1866	4.3445	4.5010
46	3.2171	3.3819	3.5456	3.7083	3.8698	4.0301	4.1892	4.3471	4.5036
47	3.2199	3.3846	3.5484	3.7110	3.8725	4.0328	4.1919	4.3497	4.5062
48	3.2227	3.3874	3.5511	3.7137	3.8752	4.0355	4.1945	4.3523	4.5088
49	3.2254	3.3901	3.5538	3.7164	3.8778	4.0381	4.1972	4.3549	4.5114
50	3.2282	3.3929	3.5565	3.7191	3.8805	4.0408	4.1998	4.3575	4.5140
51	3.2309	3.3956	3.5592	3.7218	3.8832	4.0434	4.2024	4.3602	4.5166
52	3.2337	3.3983	3.5619	3.7245	3.8859	4.0461	4.2051	4.3628	4.5192
53	3.2364	3.4011	3.5647	3.7272	3.8886	4.0488	4.2077	4.3654	4.5218
54	3.2392	3.4038	3.5674	3.7299	3.8912	4.0514	4.2104	4.3680	4.5243
55	3.2419	3.4065	3.5701	3.7326	3.8939	4.0541	4.2130	4.3706	4.5269
56	3.2447	3.4093	3.5728	3.7353	3.8966	4.0567	4.2156	4.3733	4.5295
57	3.2474	3.4120	3.5755	3.7380	3.8993	4.0594	4.2183	4.3759	4.5321
58	3.2502	3.4147	3.5782	3.7407	3.9020	4.0621	4.2209	4.3785	4.5347
59	3.2529	3.4175	3.5810	3.7434	3.9046	4.0647	4.2235	4.3811	4.5373
60	3.2557	3.4202	3.5837	3.7461	3.9073	4.0674	4.2262	4.3837	4.5399

SINE BAR TABLE—*Continued*

Min.	Constant, 27 Deg.	Constant, 28 Deg.	Constant, 29 Deg.	Constant, 30 Deg.	Constant, 31 Deg.	Constant, 32 Deg.	Constant, 33 Deg.	Constant, 34 Deg.	Constant, 35 Deg.
0	4.5399	4.6947	4.8481	5.0000	5.1504	5.2992	5.4464	5.5919	5.7358
1	4.5425	4.6973	4.8506	5.0025	5.1529	5.3017	5.4488	5.5943	5.7381
2	4.5451	4.6999	4.8532	5.0050	5.1554	5.3041	5.4513	5.5968	5.7405
3	4.5477	4.7024	4.8557	5.0076	5.1579	5.3066	5.4537	5.5992	5.7429
4	4.5503	4.7050	4.8583	5.0101	5.1604	5.3091	5.4561	5.6016	5.7453
5	4.5529	4.7076	4.8608	5.0126	5.1628	5.3115	5.4586	5.6040	5.7477
6	4.5554	4.7101	4.8634	5.0151	5.1653	5.3140	5.4610	5.6064	5.7501
7	4.5580	4.7127	4.8659	5.0176	5.1678	5.3164	5.4635	5.6088	5.7524
8	4.5606	4.7153	4.8684	5.0201	5.1703	5.3189	5.4659	5.6112	5.7548
9	4.5632	4.7178	4.8710	5.0227	5.1728	5.3214	5.4683	5.6136	5.7572
10	4.5658	4.7204	4.8730	5.0252	5.1753	5.3238	5.4708	5.6160	5.7596
11	4.5684	4.7229	4.8761	5.0277	5.1778	5.3263	5.4732	5.6184	5.7619
12	4.5710	4.7255	4.8786	5.0302	5.1803	5.3288	5.4756	5.6208	5.7643
13	4.5736	4.7281	4.8811	5.0327	5.1828	5.3312	5.4781	5.6232	5.7667
14	4.5762	4.7306	4.8837	5.0352	5.1852	5.3337	5.4805	5.6256	5.7691
15	4.5787	4.7332	4.8852	5.0377	5.1877	5.3361	5.4829	5.6280	5.7715
16	4.5813	4.7358	4.8888	5.0403	5.1902	5.3386	5.4854	5.6305	5.7738
17	4.5839	4.7383	4.8913	5.0428	5.1927	5.3411	5.4878	5.6329	5.7762
18	4.5865	4.7409	4.8938	5.0453	5.1952	5.3435	5.4902	5.6353	5.7786
19	4.5891	4.7434	4.8964	5.0478	5.1977	5.3460	5.4927	5.6377	5.7810
20	4.5917	4.7460	4.8989	5.0503	5.2002	5.3484	5.4951	5.6401	5.7833
21	4.5942	4.7486	4.9014	5.0528	5.2096	5.3509	5.4975	5.6425	5.7857
22	4.5968	4.7511	4.9040	5.0553	5.2051	5.3534	5.4999	5.6449	5.7881
23	4.5994	4.7537	4.9065	5.0578	5.2076	5.3558	5.5024	5.6473	5.7904
24	4.6020	4.7562	4.9090	5.0603	5.2101	5.3583	5.5048	5.6497	5.7928
25	4.6046	4.7588	4.9116	5.0628	5.2126	5.3607	5.5072	5.6521	5.7952
26	4.6072	4.7614	4.9141	5.0654	5.2151	5.3632	5.5097	5.6545	5.7976
27	4.6097	4.7639	4.9166	5.0679	5.2175	5.3656	5.5121	5.6569	5.7999
28	4.6123	4.7665	4.9192	5.0704	5.2200	5.3681	5.5145	5.6593	5.8023
29	4.6149	4.7690	4.9217	5.0729	5.2225	5.3705	5.5169	5.6617	5.8047
30	4.6175	4.7716	4.9242	5.0754	5.2250	5.3730	5.5194	5.6641	5.8070

31	4.6201	4.7741	4.9268	5.0779	5.2275	5.3754	5.5218	5.6665	5.8094
32	4.6226	4.7767	4.9293	5.0804	5.2299	5.3779	5.5242	5.6689	5.8118
33	4.6252	4.7793	4.9318	5.0829	5.2324	5.3804	5.5266	5.6713	5.8141
34	4.6278	4.7818	4.9344	5.0854	5.2349	5.3828	5.5291	5.6736	5.8165
35	4.6304	4.7844	4.9369	5.0879	5.2374	5.3853	5.5315	5.6760	5.8189
36	4.6330	4.7869	4.9394	5.0904	5.2399	5.3877	5.5339	5.6784	5.8212
37	4.6355	4.7895	4.9419	5.0929	5.2423	5.3902	5.5363	5.6808	5.8236
38	4.6381	4.7920	4.9445	5.0954	5.2448	5.3926	5.5388	5.6832	5.8260
39	4.6407	4.7946	4.9470	5.0979	5.2473	5.3951	5.5412	5.6856	5.8283
40	4.6433	4.7971	4.9495	5.1004	5.2498	5.3975	5.5436	5.6880	5.8307
41	4.6458	4.7997	4.9521	5.1029	5.2522	5.4000	5.5460	5.6904	5.8330
42	4.6484	4.8022	4.9546	5.1054	5.2547	5.4024	5.5484	5.6928	5.8354
43	4.6510	4.8048	4.9571	5.1079	5.2572	5.4049	5.5509	5.6952	5.8378
44	4.6536	4.8073	4.9596	5.1104	5.2597	5.4073	5.5533	5.6976	5.8401
45	4.6561	4.8099	4.9622	5.1129	5.2621	5.4097	5.5557	5.7000	5.8426
46	4.6587	4.8124	4.9647	5.1154	5.2646	5.4122	5.5581	5.7024	5.8449
47	4.6613	4.8150	4.9672	5.1179	5.2671	5.4146	5.5605	5.7047	5.8472
48	4.6639	4.8175	4.9697	5.1204	5.2696	5.4171	5.5630	5.7071	5.8396
49	4.6664	4.8201	4.9723	5.1229	5.2720	5.4195	5.5654	5.7095	5.8519
50	4.6690	4.8226	4.9748	5.1254	5.2745	5.4220	5.5678	5.7119	5.8543
51	4.6716	4.8252	4.9773	5.1279	5.2770	5.4244	5.5702	5.7143	5.8567
52	4.6742	4.8277	4.9798	5.1304	5.2794	5.4269	5.5726	5.7167	5.8590
53	4.6767	4.8303	4.9824	5.1329	5.2819	5.4293	5.5750	5.7191	5.8614
54	4.6793	4.8328	4.9849	5.1354	5.2844	5.4317	5.5775	5.7215	5.8637
55	4.6819	4.8354	4.9874	5.1379	5.2869	5.4342	5.5799	5.7238	5.8661
56	4.6844	4.8379	4.9899	5.1404	5.2893	5.4366	5.5823	5.7262	5.8684
57	4.6870	4.8405	4.9924	5.1429	5.2918	5.4391	5.5847	5.7286	5.8708
58	4.6896	4.8430	4.9950	5.1454	5.2943	5.4415	5.5871	5.7310	5.8731
59	4.6921	4.8456	4.9975	5.1479	5.2967	5.4440	5.5895	5.7334	5.8755
60	4.6947	4.8481	5.0000	5.1504	5.2992	5.4464	5.5919	5.7358	5.8779

SINE BAR TABLE—*Continued*

Min.	Constant, 36 Deg.	Constant, 37 Deg.	Constant, 38 Deg.	Constant, 39 Deg.	Constant, 40 Deg.	Constant, 41 Deg.	Constant, 42 Deg.	Constant, 43 Deg.	Constant, 44 Deg.
0	5.8779	6.0182	6.1566	6.2932	6.4279	6.5606	6.6913	6.8200	6.9466
1	5.8802	6.0205	6.1589	6.2955	6.4301	6.5628	6.6935	6.8221	6.9487
2	5.8826	6.0228	6.1612	6.2977	6.4323	6.5650	6.6956	6.8242	6.9508
3	5.8849	6.0251	6.1635	6.3000	6.4346	6.5672	6.6978	6.8264	6.9529
4	5.8873	6.0274	6.1658	6.3022	6.4368	6.5694	6.6999	6.8285	6.9549
5	5.8896	6.0298	6.1681	6.3045	6.4390	6.5716	6.7021	6.8306	6.9570
6	5.8920	6.0321	6.1704	6.3068	6.4412	6.5738	6.7043	6.8327	6.9591
7	5.8943	6.0344	6.1726	6.3090	6.4435	6.5759	6.7064	6.8349	6.9612
8	5.8967	6.0367	6.1749	6.2113	6.4457	6.5781	6.7086	6.8370	6.9633
9	5.8990	6.0390	6.1772	6.3136	6.4479	6.5803	6.7107	6.8391	6.9654
10	5.9014	6.0414	6.1795	6.3158	6.4501	6.5825	6.7129	6.8412	6.9675
11	5.9037	6.0437	6.1818	6.3180	6.4524	6.5847	6.7151	6.8434	6.9690
12	5.9061	6.0460	6.1841	6.3203	6.4546	6.5869	6.7172	6.8455	6.9717
13	5.9084	6.0483	6.1864	6.3225	6.4568	6.5891	6.7194	6.8476	6.9737
14	5.9108	6.0506	6.1887	6.3248	6.4590	6.5913	6.7215	6.8497	6.9758
15	5.9131	6.0529	6.1909	6.3271	6.4612	6.5935	6.7237	6.8518	6.9779
16	5.9154	6.0553	6.1932	6.3293	6.4635	6.5956	6.7258	6.8539	6.9800
17	5.9178	6.0576	6.1965	6.3316	6.4657	6.5978	6.7280	6.8561	6.9821
18	5.9201	6.0599	6.1978	6.3338	6.4679	6.6000	6.7301	6.8582	6.9842
19	5.9225	6.0622	6.2001	6.3361	6.4701	6.6022	6.7323	6.8603	6.9862
20	5.9248	6.0645	6.2024	6.3383	6.4723	6.6044	6.7344	6.8624	6.9885
21	5.9272	6.0668	6.2046	6.3400	6.4746	6.6066	6.7366	6.8645	6.9904
22	5.9295	6.0691	6.2069	6.3428	6.4768	6.6088	6.7387	6.8666	6.9925
23	5.9318	6.0714	6.2092	6.3451	6.4790	6.6109	6.7409	6.8688	6.9946
24	5.9342	6.0738	6.2115	6.3473	6.4812	6.6131	6.7430	6.8709	6.9966
25	5.9365	6.0761	6.2138	6.3496	6.4834	6.6153	6.7452	6.8730	6.9987
26	5.9389	6.0784	6.2160	6.3518	6.4856	6.6175	6.7473	6.8751	7.0008
27	5.9412	6.0807	6.2183	6.3540	6.4878	6.6197	6.7495	6.8772	7.0029
28	5.9436	6.0830	6.2206	6.3563	6.4901	6.6218	6.7516	6.8793	7.0049
29	5.9459	6.0853	6.2229	6.3585	6.4923	6.6240	6.7538	6.8814	7.0070
30	5.9482	6.0876	6.2251	6.3608	6.4945	6.6262	6.7559	6.8835	7.0091

31	5.9506	6.0899	6.2274	6.3630	6.4967	6.6284	6.7580	6.8857	7.0112
32	5.9529	6.0922	6.2297	6.3653	6.4989	6.6306	6.7602	6.8878	7.0132
33	5.9552	6.0945	6.2320	6.3675	6.5011	6.6327	6.7623	6.8899	7.0153
34	5.9576	6.0968	6.2342	6.3698	6.5033	6.6349	6.7645	6.8920	7.0174
35	5.9599	6.0991	6.2365	6.3720	6.5055	6.6371	6.7666	6.8941	7.0195
36	5.9622	6.1015	6.2388	6.3742	6.5077	6.6393	6.7688	6.8962	7.0215
37	5.9646	6.1038	6.2411	6.3765	6.5100	6.6414	6.7709	6.8983	7.0236
38	5.9669	6.1061	6.2433	6.3787	6.5122	6.6436	6.7730	6.9004	7.0257
39	5.9693	6.1084	6.2456	6.3810	6.5144	6.6458	6.7752	6.9025	7.0277
40	5.9716	6.1107	6.2479	6.3832	6.5166	6.6480	6.7773	6.9046	7.0298
41	5.9739	6.1130	6.2502	6.3854	6.5188	6.6501	6.7795	6.9067	7.0319
42	5.9763	6.1153	6.2524	6.3877	6.5210	6.6523	6.7816	6.9088	7.0339
43	5.9786	6.1176	6.2547	6.3899	6.5232	6.6545	6.7837	6.9109	7.0360
44	5.9809	6.1199	6.2570	6.3922	6.5254	6.6566	6.7859	6.9130	7.0381
45	5.9832	6.1222	6.2592	6.3944	6.5276	6.6588	6.7880	6.9151	7.0401
46	5.9856	6.1245	6.2615	6.3966	6.5298	6.6610	6.7901	6.9172	7.0422
47	5.9879	6.1268	6.2638	6.2989	6.5320	6.6632	6.7923	6.9193	7.0443
48	5.9902	6.1291	6.2660	6.4011	6.5342	6.6653	6.7944	6.9214	7.0463
49	5.9926	6.1314	6.2683	6.4033	6.5364	6.6675	6.7965	6.9235	7.0484
50	5.9949	6.1337	6.2706	6.4056	6.5386	6.6697	6.7987	6.9256	7.0505
51	5.9972	6.1360	6.2728	6.4078	6.5408	6.6718	6.8008	6.9277	7.0525
52	5.9995	6.1383	6.2751	6.4100	6.5430	6.6740	6.8029	6.9298	7.0546
53	6.0019	6.1406	6.2774	6.4123	6.5452	6.6762	6.8051	6.9319	7.0567
54	6.0042	6.1429	6.2796	6.4145	6.5474	6.6783	6.8072	6.9340	7.0587
55	6.0065	6.1451	6.2819	6.4167	6.5496	6.6805	6.8093	6.9361	7.0608
56	6.0089	6.1474	6.2842	6.4190	6.5518	6.6827	6.8115	6.9382	7.0628
57	6.0112	6.1497	6.2864	6.4212	6.5540	6.6848	6.8136	6.9403	7.0649
58	6.0135	6.1520	6.2887	6.4234	6.5562	6.6870	6.8157	6.9424	7.0670
59	6.0158	6.1543	6.2909	6.4256	6.5584	6.6891	6.8179	6.9445	7.0690
60	6.0182	6.1566	6.2932	6.4279	6.5606	6.6913	6.8200	6.9466	7.0711

of locating work at the desired angle upon an angle plate or other plate so that the work may be set at once to the desired angle for laying out, drilling, or machining otherwise. It is customary to locate the discs on the sine bar at a center distance of either 5 or 10 inches, these being convenient lengths and, moreover, forming handy figures for multiplying the quantities for the corresponding angles, as taken from a table of sines, in setting the sine bar in position.

The discs are used for setting the bar at the correct angle by measuring up under the discs with a vernier height gage, the bar then being clamped securely to the angle plate. With the sine bar in Fig. 11, the discs are large enough to project over the edges of the bar so that the lower disc always rests directly upon the surface plate or upon a parallel on the plate, and the sine bar may be set very easily as it is merely swung upon its lower disc until the upper disc is at the right height as determined by the height gage.

Use of the Special Table

It is a convenience in using the sine bar to have a special table computed to cover degrees and minutes with sines calculated for a radius of 10; that is, the quantities are ten times the sines as taken from a regular table of sines. Thus, in the accompanying table the constants are figured for direct setting of the 10-inch sine bar. If a 5-inch bar is used these constants should be divided by two.

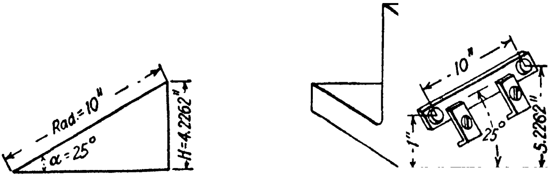


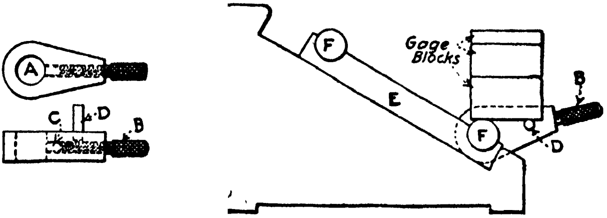
FIG. 12 FIG. 13

Using the Sine Bar

Suppose, in Fig. 12, it is desired to set the bar at an angle of 25 degrees, as indicated in the sketch in Fig. 13. In the triangle, Fig. 12, the radius, 10 inches, is the center distance between the sine-bar discs, and the dimension required to be found is the height *H*. Referring to our table herewith, we find opposite the angle 25 degrees, the constant 4.2262, so that the height of the center of the upper disc must be 4.2262 inches above the lower disc. In Fig. 13 the sine bar is shown set with the lower disc center 1 inch above the surface plate as a matter of convenience so that the other disc must be set 4.2262 inches plus 1 inch or a center height of 5.2262 inches. With the form of sine bar in Fig. 13, when the lower disc rests directly upon a surface plate, the setting for the upper disc would be 4.2262 plus ½ inch or 4.7262 inches.

Attachment for Use with the Sine Bar

The attachment illustrated in Fig. 14 was developed to be used with Johansson blocks in connection with the sine bar for more accurate setting or testing of angles than is usually obtained with the height gage. It is shown in use in measuring the angle on the shoe for an angular jig.



FIGS. 14 and 15.—Attachment for Use with the Sine Bar

The body of the attachment is made of machine steel. The large hole *A* is a slip fit for the plug of the sine bar. The knurled head screw *B* and the brass button *C* provide means for clamping. The small pin *D* driven into the machine-steel body on which one end of the gage blocks rests when in use completes the attachment.

In Fig. 15, the sine bar *E* has the plugs *F* extending beyond the bar on both sides and clear on the tops.

In use, the attachment is slipped over one of the plugs with the pin *D* pointed in. The sine bar is clamped on to the piece to be tested, and the required combination of blocks placed so as to rest on top of the plug of the sine bar and the pin of the attachment; with the aid of an indicator the blocks are then set parallel with the surface plate, adjustment being made by tapping the attachment up or down as required.

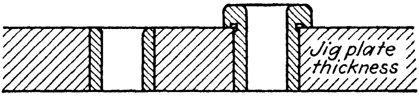
After the blocks are set parallel, all that is necessary is to run the indicator over the higher plug of the sine bar and the top surface of blocks to determine the accuracy of the setting.

SECTION XVIII

SHOP AND DRAWING-ROOM STANDARDS

STANDARD JIG BUSHINGS

Jig bushings have now been standardized and can be purchased from a number of makers. Bushings are divided into three types: press-fit bushings, which are forced directly into a jig and guide the drill or bar; liner bushings which are also forced into the jig and which carry renewable bushings for guiding the tools—sometimes called "master bushings"; press-fit and liner bushings are made both with and without heads. Renewable bushings have heads of either plain or knurled types. The way in which these bushings are used is shown in Fig. 1. The tables give dimensions as revised in August, 1941.



Headless Type Shoulder Head Type

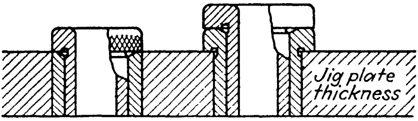


FIG. 1.—Types of bushings

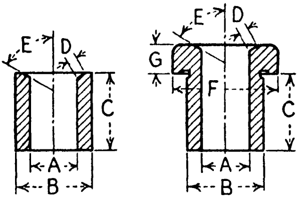
Jig plate thickness has been standardized as shown in body length C^4 of press-fit bushings in Table 1. Renewable bushings length depends on the bushing in which it fits.

Grinding allowance is

0.005 to 0.010 inch for $\frac{5}{32}$, $\frac{13}{64}$, and $\frac{1}{4}$ inch
0.010 to 0.015 inch for $\frac{5}{16}$ and $\frac{13}{32}$ inch
0.015 to 0.020 inch for $\frac{1}{2}$ inch and over

Changes have been proposed in the body diameters of bushings but have not been adopted as yet. These include both finished and unfinished outside diameters, the unfinished bushings to have grinding allowances of from 0.005 inch on the smallest to 0.020 on $\frac{1}{2}$ inch and larger. The unfinished sizes from $\frac{1}{2}$ inch to $2\frac{1}{4}$ inches are the same as given in Table 1. If and when these proposed changes are adopted, new tables can be secured from the American Standards Association, 29 West 39th Street, New York.

TABLE 1.—PRESS-FIT WEARING BUSHINGS—HEADLESS AND SHOULDER-HEAD TYPES



Press Fit, Headless Wearing Bushing Press Fit, Head Type Wearing Bushing

Range of Hole Size $A^{1,2}$ in Inches		Body Diameter[3] *B*, in Inches			Body Length C^4, in Inches			Width of Chamfer[5] *D*, in Inches	Maximum Head[6] Diameter *E*, in Inches	Maximum Head[6] Height *G*, in Inches
From	Up to and Including	Nominal	Maximum	Minimum	Short	Medium	Long			
0.0156	0.0625	5/32	0.176	0.171	5/16		1/2	1/32	1/4	3/32
0.0630	0.0995	13/64	0.223	0.218	5/16		1/2	1/32	5/16	3/32
0.1024	0.1378	1/4	0.270	0.265	5/16		1/2	1/32	3/8	3/32
0.1406	0.1875	5/16	0.333	0.328	5/16	1/2	3/4	1/32	7/16	1/8
0 1910	0 2500	13/32	0.426	0.421	5/16	1/2	3/4	1/16	17/32	5/32
0.2520	0 3125	1/2	0 520	0.515	5/16	1/2	3/4	5/64	5/8	7/32
0.3160	0 4219	5/8	0.645	0 640	1/2	3/4	1	3/32	13/16	7/32
0.4375	0 5000	3/4	0.770	0 765	1/2	3/4	1	7/64	15/16	7/32
0.5156	0.6250	7/8	0.895	0.890	3/4	1	1 3/8	7/64	1 1/8	1/4
0.6406	0 7500	1	1.020	1.015	3/4	1	1 3/8	7/64	1 1/4	5/16
0.7656	1.0000	1 3/8	1.395	1.390	3/4	1	1 3/8	9/64	1 5/8	3/8
1.0156	1.3750	1 3/4	1.770	1.765	1	1 3/8	1 3/4	9/64	2	3/8
1.3906	1.7500	2 1/4	2.270	2.265	1	1 3/8	1 3/4	7/32	2 1/2	3/8

All dimensions given in inches.

Tolerance on fractional dimensions, where not otherwise specified, shall be +0.010 inch.

[1] Hole sizes are in accordance with the proposed American standard for twist-drill sizes.

[2] The maximum and minimum values of the hole size, *A*, shall be as follows:

Nominal Size of Hole, in Inches	Maximum, in Inches	Minimum, in Inches
Above 0.0000 to 1/4 incl.	Nominal +0.0004 in.	Nominal +0.0001 in.
Above 1/4 to 3/4 incl.	Nominal +0.0005 in.	Nominal +0.0001 in.
Above 3/4 to 1/2 incl.	Nominal +0.0006 in.	Nominal +0.0002 in.
Above 1 1/2	Nominal +0.0007 in.	Nominal +0.0003 in.

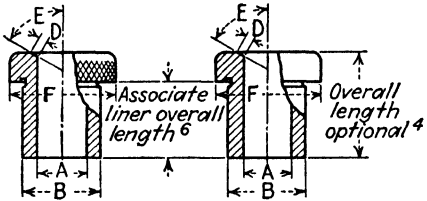
[3] The minimum body diameter *B* is 0.015 to 0.020 inch larger than the nominal diameter in order to provide grinding stock for fitting to jig-plate holes.

[4] The length *C* is the over-all length for the headless type and the length underhead for the head type.

[5] The angle of chamfer *E* shall be 59 degrees ± 1 degree, and a slight radius shall be provided at the intersection of this chamfer with the hole *A*.

[6] The head design shall be in accordance with the manufacturer's practice.

TABLE 2.—RENEWABLE WEARING BUSHINGS—SLIP AND PLAIN SHOULDER-HEAD TYPES



Slip Type, Renewable[5] Wearing Bushing   Plain Type, Renewable Wearing Bushing

(Tolerance on fractional dimensions where not otherwise specified shall be ±0.010 inch)

Range of Hole*† Size *A*		Body Diameter *B*			Width of Chamfer‡ *D*	Maximum Head§ Diameter *F*
From	Up to and Including	Nominal	Maximum	Minimum		
0.0000	0.1562	5/16	0.3125	0.3123	1/32	5/8
0.1610	0.3125	1/2	0.5000	0.4998	5/64	13/16
0.3160	0.5000	3/4	0.7500	0.7498	7/64	1 1/4
0.5156	0.7500	1	1.0000	0.9998	7/64	1 5/8
0.7656	1.0000	1 3/8	1.3750	1.3747	9/64	2
1.0156	1.3750	1 3/4	1.7500	1.7497	9/64	2 1/2
1.3906	1.7500	2 1/4	2.2500	2.2496	7/32	3

* Hole sizes are in accordance with the proposed American Standard for twist-drill sizes.

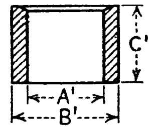
† The maximum and minimum values of hole size *A* shall be as follows:

Nominal Size of Hole, in Inches	Maximum, in Inches	Minimum, in Inches
Above 0.0000 to 1/4 incl.	Nominal +0.0004	Nominal +0.0001
Above 1/4 to 3/4 incl.	Nominal +0.0005	Nominal +0.0001
Above 3/4 to 1/2 incl.	Nominal +0.0006	Nominal +0.0002
Above 1 1/2	Nominal +0.0007	Nominal +0.0003

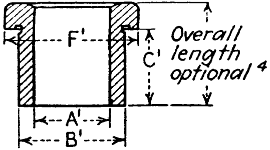
‡ The angle of chamfer *E* shall be 59 degrees ± 1 degree, and a slight radius shall be provided at the intersection of this chamfer with the hole *A*.

§ The head design shall be in accordance with the manufacturer's practice. Head of slip type is usually knurled.

When renewable wearing bushings are used with liner bushings of the head type, the length under the head should be increased over the jig-plate thickness by the thickness of the liner bushing head.



Headless Liner Bushing



Head Type Liner Bushing

TABLE 3.—LINER BUSHINGS—HEADLESS AND SHOULDER-HEAD TYPE

(Tolerance on fractional dimensions where not otherwise specified shall be ±0.010 inch)

Range of Hole Size in Renewable Wearing Bushing*		Inside Diameter *A'*			Body Diameter† *B'*			Jig-Plate‡ Thickness *C'*			*F'* Max. Head Diameter§
From	Up to and Including	Nominal	Maximum	Minimum	Nominal	Maximum	Minimum	Short	Medium	Long	
0.0000	0.1562	$\frac{5}{16}$	0.3129	0.3126	$\frac{1}{2}$	0.520	0.515	$\frac{5}{16}$	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{5}{8}$
0.1610	0.3125	$\frac{1}{2}$	0.5005	0.5002	$\frac{3}{4}$	0.770	0.765	$\frac{5}{16}$	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{15}{16}$
0.3160	0.5000	$\frac{3}{4}$	0.7506	0.7503	1	1.020	1.015	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{4}$
0.5156	0.7500	1	1.0007	1.0004	$1\frac{3}{8}$	1.395	1.390	$\frac{3}{4}$	1	$1\frac{3}{8}$	$1\frac{5}{8}$
0.7656	1.0000	$1\frac{3}{8}$	1.3760	1.3756	$1\frac{3}{4}$	1.770	1.765	$\frac{3}{4}$	1	$1\frac{3}{8}$	2
1.0156	1.3750	$1\frac{3}{4}$	1.7512	1.7508	$2\frac{1}{4}$	2.270	2.265	1	$1\frac{3}{8}$	$1\frac{3}{4}$	$2\frac{1}{2}$
1.3906	1.7500	$2\frac{1}{4}$	2.2515	2.2510	$2\frac{3}{4}$	2.770	2.765	1	$1\frac{3}{8}$	$1\frac{3}{4}$	3

* For detail dimensions of renewable wearing bushings, see Table 2.

† The minimum body diameter *B'* is 0.015 to 0.020 inch larger than the nominal diameter in order to provide grinding stock for fitting to jig-plate holes.

‡ The length *C'* is the over-all length for the headless type and the length under head for the head type.

§ The head design shall be in accordance with the manufacturer's practice.

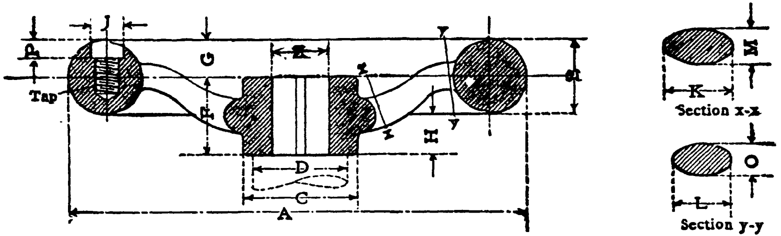
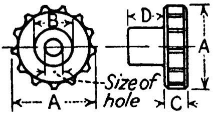


TABLE 4.—HAND WHEELS. (Pratt & Whitney Co.)

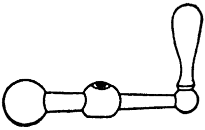
A	B	C	D	E	F	G	H	J	K	L	M	O	P	Tap	Spline	Handle No.	No. of Arms
3 in.	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{5}{8}$	$\frac{3}{8}$	$\frac{9}{16}$	$\frac{5}{16}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{15}{32}$	$\frac{11}{32}$	$\frac{1}{4}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{5}{16}$ — 28	$\frac{1}{16} \times \frac{1}{32}$	00	3
4	$\frac{11}{16}$	$\frac{13}{16}$	$\frac{3}{4}$	$\frac{3}{8}$	$\frac{5}{8}$	$\frac{15}{32}$	$\frac{13}{32}$	$\frac{15}{32}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{11}{32}$	$\frac{7}{32}$	$\frac{1}{4}$	$\frac{5}{16}$ — 28	$\frac{1}{16} \times \frac{1}{32}$	0	3
$4\frac{1}{2}$	$\frac{7}{8}$	$1\frac{1}{8}$	1	$\frac{7}{16}$	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{15}{32}$	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{11}{32}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{8}$ — 24	$\frac{3}{32} \times \frac{3}{64}$	1	3
5	$\frac{7}{8}$	$1\frac{3}{16}$	$1\frac{1}{16}$	$\frac{9}{16}$	$\frac{7}{8}$	$\frac{15}{32}$	$\frac{15}{32}$	$\frac{15}{32}$	$\frac{7}{8}$	$\frac{5}{8}$	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{8}$ — 24	$\frac{3}{32} \times \frac{3}{64}$	1	3
6	1	$1\frac{1}{4}$	$1\frac{1}{8}$	$\frac{9}{16}$	1	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{15}{16}$	$\frac{11}{16}$	$\frac{1}{2}$	$\frac{11}{32}$	$\frac{5}{16}$	$\frac{3}{8}$ — 24	$\frac{1}{8} \times \frac{1}{16}$	2	3
7	1	$1\frac{1}{2}$	$1\frac{3}{8}$	$\frac{11}{16}$	1	$\frac{13}{16}$	$\frac{11}{16}$	$\frac{19}{32}$	$\frac{15}{16}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{5}{16}$	$\frac{3}{8}$ — 24	$\frac{1}{8} \times \frac{1}{16}$	3	3
8	$1\frac{1}{8}$	$1\frac{13}{16}$	$1\frac{5}{8}$	1	1	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{19}{32}$	1	$\frac{5}{8}$	$\frac{9}{16}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$ — 24	$\frac{1}{8} \times \frac{1}{16}$	4	3
9	$1\frac{1}{8}$	$1\frac{7}{8}$	$1\frac{3}{4}$	1	1	1	$\frac{7}{8}$	$\frac{19}{32}$	$1\frac{1}{8}$	$\frac{3}{4}$	$\frac{9}{16}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$ — 24	$\frac{1}{8} \times \frac{1}{16}$	4	3
10	$1\frac{1}{4}$	$1\frac{15}{16}$	$1\frac{11}{16}$	$\frac{7}{8}$	1	$1\frac{1}{4}$	1	$\frac{21}{32}$	$1\frac{3}{16}$	$\frac{7}{8}$	$\frac{5}{8}$	$\frac{7}{16}$	$\frac{7}{16}$	$\frac{7}{16}$ — 20	$\frac{3}{16} \times \frac{3}{32}$	5	3
11	$1\frac{1}{4}$	$1\frac{15}{16}$	$1\frac{11}{16}$	$\frac{7}{8}$	1	$1\frac{5}{16}$	$1\frac{1}{16}$	$\frac{21}{32}$	$1\frac{3}{8}$	1	$\frac{5}{8}$	$\frac{7}{16}$	$\frac{7}{16}$	$\frac{7}{16}$ — 20	$\frac{3}{16} \times \frac{3}{32}$	5	3
12	$1\frac{7}{16}$	2	$1\frac{7}{8}$	$\frac{7}{8}$	$1\frac{1}{4}$	$1\frac{3}{16}$	1	$\frac{3}{4}$	$1\frac{7}{16}$	$1\frac{1}{16}$	$\frac{11}{16}$	$\frac{9}{16}$	$\frac{7}{16}$	$\frac{1}{2}$ — 16	$\frac{3}{16} \times \frac{3}{32}$	6	3

TABLE 5.—MALLEABLE-IRON JIG KNOBS (In Inches)



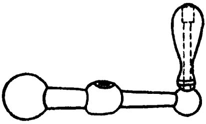
Size of Hole	A	B	C	D
1/4	1 1/2	3/4	3/8	1/2
5/16	1 1/2	3/4	3/8	1/2
3/8	1 1/2	3/4	3/8	1/2
7/16	1 1/2	3/4	3/8	1/2
1/2	2	1 1/16	1/2	1/2
9/16	2	1 1/16	1/2	1/2
5/8	2	1 1/16	1/2	1/2
3/4	2 1/2	1 1/4	5/8	5/8
7/8	2 1/2	1 1/4	5/8	5/8

TABLE 6.—BALL CRANKS, SOLID HANDLES



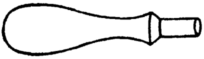
Size	Length over All, in Inches	Center ball, in Inches	Large-End Ball, in Inches	Small-End Ball, in Inches
0	3	7/8	1	5/8
1	3 1/2	1	1 1/8	3/4
1 1/2	4	1 1/8	1 1/4	13/16
2	4 1/2	1 1/4	1 3/8	15/16
3	5	1 5/16	1 1/2	1
4	5 1/2	1 5/16	1 1/2	1
5	6	1 3/8	1 5/8	1
6	6 1/2	1 3/8	1 5/8	1
7	7	1 7/16	1 3/4	1
8	7 1/2	1 1/2	1 3/4	1
9	8	1 1/2	1 3/4	1 1/16
10	8 1/2	1 9/16	1 3/4	1 1/8
12	11	1 13/16	2	1 1/4
13	13	1 15/16	2	1 1/4

TABLE 7.—REVOLVING HANDLES



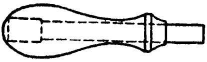
Size	Length over All, in Inches	Center Ball, in Inches	Large-End Ball, in Inches	Small-End Ball, in Inches
1	3 1/2	1	1 1/8	3/4
1 1/2	4	1 1/8	1 1/4	13/16
2	4 1/2	1 1/4	1 3/8	15/16
3	5	1 5/16	1 1/2	1
4	5 1/2	1 5/16	1 1/2	1
5	6	1 3/8	1 5/8	1
6	6 1/2	1 3/8	1 5/8	1
7	7	1 7/16	1 3/4	1
8	7 1/2	1 1/2	1 3/4	1
9	8	1 1/2	1 3/4	1 1/16
10	8 1/2	1 9/16	1 3/4	1 1/8
12	11	1 13/16	2	1 1/4
13	13	1 15/16	2	1 1/4

TABLE 8.—MACHINE HANDLES



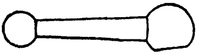
Size	Length of Shank, in Inches	Length over All, in Inches	Diameter of Shank, in Inches
000	7/16	1 23/32	1/4
00	7/16	1 29/32	1/4
0	7/16	2 5/32	5/16
1/2	7/16	2 7/16	5/16
1	9/16	2 11/16	3/8
2	11/16	3 1/16	7/16
3	11/16	3 7/16	7/16
4	11/16	3 29/32	7/16
5	13/16	4 1/4	7/16
6	15/16	4 9/16	1/2
7	15/16	5	1/2
8	1 3/16	5 3/4	5/8

TABLE 9.—REVOLVING MACHINE HANDLES



Size	Length of Shank, in Inches	Diameter of Shank, in Inches	Length over All, in Inches
1	9/16	5/16	2⅝
3	¾	⅜	3 25/32
4	¾	7/16	4 1/32
7	1	½	5⅛

TABLE 10.—TWO BALL LEVERS



Size	Length over All, in Inches	Large-End Ball, in Inches	Small-End Ball, in Inches
1	3½	1⅛	¾
1½	4	1¼	13/16
2	4½	1⅜	15/16
3	5	1½	1
4	5½	1½	1
6	6½	1¾	1
7	7	1¾	1
10	8½	1¾	1⅛

Balcrank Handle Specification Tolerances

Machine handles, shank diameter	+0.001 to +0.003
Machine handles, shank length	−0.005 to +0.005
On machining of center or end balls:	
Holes up to and including 5 inch	−0.0005 to +0.001
Holes over ⅝ inch	−0.0005 to +0.0015
Thickness from face to face	−0.0050 to +0.0050
Keyway width	−0.0000 to +0.0005
Keyway depth	−0.0000 to +0.0080
Diameter of faces	−0.0156 to +0.0156

Limits cannot be held on thickness of ball and both face diameters. Specify only two of these diameters. Do not specify close tolerances where they are not needed; it is an economic waste.

FITTING BALL AND ROLLER BEARINGS

Users of ball and roller bearings are interested in the fitting of the bearings into machines rather than detailed dimensions of the bearings themselves. Table 11 gives this information in concise form. Similar tolerances apply to other bearings of similar types.

TABLE 11.—TOLERANCES AND FITS FOR NEW DEPARTURE RADAX BEARING MOUNTINGS

Basic Bearing Numbers	Bearing Bore				Shaft Revolving				Shaft Stationary			
	Diameters		Tolerances		Diameters		Fits		Diameters		Fits	
	Maximum	Minimum	+	−	Maximum	Minimum	Tight	Loose	Maximum	Minimum	Tight	Loose
201	0.4724	0.4720	0.0000	0.0004	0.4727	0.4724	0.0007	0.0000	0.4720	0.4717	0.0000	0.0007
202	0.5906	0.5902	0.0000	0.0004	0.5909	0.5906	0.0007	0.0000	0.5902	0.5899	0.0000	0.0007
203 303	0.6693	0.6689	0.0000	0.0004	0.6696	0.6693	0.0007	0.0000	0.6689	0.6686	0.0000	0.0007
304 404	0.7874	0.7870	0.0000	0.0004	0.7877	0.7874	0.0007	0.0000	0.7870	0.7867	0.0000	0.0007
305 405	0.9843	0.9839	0.0000	0.0004	0.9846	0.9843	0.0007	0.0000	0.9839	0.9836	0.0000	0.0007
206 306 406	1.1811	1.1807	0.0000	0.0004	1.1814	1.1811	0.0007	0.0000	1.1708	1.1804	0.0000	0.0007
207 307 407	1.3780	1.3775	0.0000	0.0005	1.3783	1.3779	0.0008	0.0001	1.3776	1.3772	0.0001	0.0008
208 308 408	1.5748	1.5748	0.0000	0.0005	1.5751	1.5747	0.0008	0.0001	1.5744	1.5740	0.0001	0.0008

209 309 409	1.7717	1.7712	0.0000	0.0005	1.7720	1.7716	0.0008	0.0001	1.7713	1.7709	0.0001	0.0008
210 310	1.9685	1.9680	0.0000	0.0005	1.9688	1.9684	0.0008	0.0001	1.9681	1.9677	0.0001	0.0008
211 311	2.1654	2.1648	0.0000	0.0006	2.1658	2.1653	0.0010	0.0001	2.1649	2.1644	0.0001	0.0010
212 312 412	2.3622	2.3616	0.0000	0.0006	2.3626	2.3621	0.0010	0.0001	2.3617	2.3612	0.0001	0.0010
213 313	2.5591	2.5585	0.0000	0.0006	2.5595	2.5590	0.0010	0.0001	2.5586	2.5581	0.0001	0.0010
214	2.7559	2.7553	0.0000	0.0006	2.7563	2.7558	0.0010	0.0001	2.7554	2.7549	0.0001	0.0010
215 315	2.9528	2.9522	0.0000	0.0006	2.9532	2.9527	0.0010	0.0001	2.9523	2.9518	0.0001	0.0010
216	3.1496	3.1490	0.0000	0.0006	3.1500	3.1495	0.0010	0.0001	3.1491	3.1486	0.0001	0.0010
217	3.3465	3.3458	0.0000	0.0007	3.3469	3.3463	0.0011	0.0002	3.3460	3.3454	0.0002	0.0011
218	3.5433	3.5426	0.0000	0.0007	3.5437	3.5431	0.0011	0.0002	3.5428	3.5422	0.0002	0.0011
219	3.7402	3.7395	0.0000	0.0007	3.7406	3.7400	0.0011	0.0002	3.7397	3.7391	0.0002	0.0011
220	3.9370	3.9363	0.0000	0.0007	3.9374	3.9368	0.0011	0.0002	3.9365	3.9359	0.0002	0.0011

TABLE 12.—TOLERANCES IN FITTING BOWER ROLLER BEARINGS—SEE PAGE 842

Bearing Bore	Bore Tolerance	Rotating Shaft				Stationary Shaft	
		Adjustable Cone		Nonadjustable Cone		Adjustable and Nonadjustable Cone	
		Shaft Tolerance	Fit	Shaft Tolerance	Fit	Shaft Tolerance	Fit
Up to 1¼ inches	+0.0005 −0.0000	+0.0005 −0.0000	0.0005 T 0.0005 L	+0.0015 +0.0010	0.0015 T 0.0005 T	+0.0000 −0.0005	0.0000 T 0.0010 L
1¼ to 2⅜ inches		+0.0008 −0.0000	0.0008 T 0.0005 L	+0.0018 +0.0010	0.0018 T 0.0005 T	+0.0000 −0.0008	0.0000 T 0.0013 L
2⅜ inches and up	+0.0010 −0.0000	+0.0010 −0.0000	0.0010 T 0.0010 L	+0.0025 +0.0015	0.0025 T 0.0005 T	+0.0000 −0.0010	0.0000 T 0.0020 L

Bearing O.D.	O.D. Tolerance	Stationary or Rotating Housing			
		Adjustable Cup*		Nonadjustable Cup	
		Housing Tolerance	Fit	Housing Tolerance	Fit
Up to 3 inches	+0.0010 −0.0000	+0.0010 −0.0000	0.0010 T 0.0010 L	−0.0005 −0.0015	0.0025 T 0.0005 T
3 to 5 inches		+0.0015 −0.0000	0.0010 T 0.0015 L	−0.0010 −0.0025	0.0035 T 0.0005 T
5 to 7 inches		+0.0020 −0.0000	0.0010 T 0.0020 L	−0.0010 −0.0030	0.0040 T 0.0010 T

Metric Straight Roller Bearings

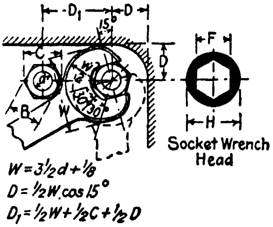
Basic Bearing No.	Bore Tolerance	Rotating Shaft		Stationary Shaft	
		Shaft Tolerance	Fit	Shaft Tolerance	Fit *
4–6	+0.0000 −0.0004	+0.0007 +0.0003	0.0011 T 0.0003 T	−0.0003 −0.0008	0.0001 T 0.0008 L
7–10	+0.0000 −0.0005	+0.0008 +0.0003	0.0013 T 0.0003 T	−0.0004 −0.0010	0.0001 T 0.0010 L
11	+0.0000 −0.0006	+0.0010 +0.0004	0.0016 T 0.0004 T	−0.0004 −0.0011	0.0002 T 0.0011 L

Basic Bargaining No.		O.D. Tolerance	Stationary Housing		Rotating Housing	
Light	Medium		Housing Tolerance	Fit	Housing Tolerance	Fit
5–8	4–7	+0.0000 −0.0006	+0.0004 −0.0002	0.0002 T 0.0010 L	−0.0004 −0.0010	0.0010 T 0.0002 T
9–11	9–10	+0.0000 −0.0008	+0.0006 −0.0002	0.0002 T 0.0014 L	−0.0005 −0.0013	0.0013 T 0.0003 L

---

* It is recommended that adjustable cups be clamped in place after adjustment to avoid loose fits especially in rotating housings, or that the cup be mounted with a press fit in an adjustable cup carrier which can be rigidly bolted or locked in place. It is also better construction to secure adjustable cones solidly in place, once the original adjustment is established.

Minimum Spacing of Hexagon Nuts for Wrench Clearance



This shows the minimum spacing for wrench clearance of bolts with hexagon nuts; also the sizes for standard socket-wrench heads, diameter of spot-facing cutters, washers and other information on bolts. To spotface where washers are used, add ⅛ in. to washer diam. for diam. of cutter to use.

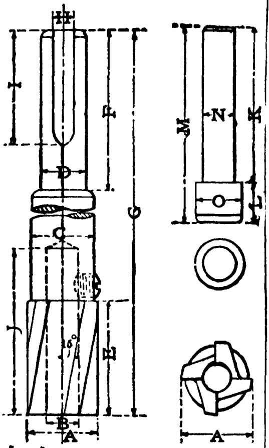
TABLE 13.—OPEN-END AND SOCKET-WRENCH HEADS
(In Inches)

Bolt Diam. U.S.S. d	D	D1	Diam. Spot-facing Cutter	Diam. U. S. S. Washer	Over Flats B	Across Corner C	Socket F	Wrench H
1/4	1/2	1	3/4	3/4	1/2	.578	33/64	3/4
5/16	19/32	1 3/16	7/8	7/8	19/32	.686	39/64	7/8
3/8	11/16	1 3/8	1	1	11/16	.794	45/64	1 1/8
7/16	13/16	1 9/16	1 1/8	1 1/4	25/32	.902	51/64	1 1/4
1/2	29/32	1 13/16	1 1/4	1 3/8	7/8	1.011	57/64	1 3/8
9/16	1	2	1 3/8	1 1/2	31/32	1.119	63/64	1 1/2
5/8	1 1/8	2 3/16	1 1/2	1 3/4	1 1/16	1.227	1 5/64	1 5/8
3/4	1 11/32	2 9/16	1 3/4	2	1 1/4	1.444	1 9/32	1 7/8
7/8	1 9/16	2 15/16	1 7/8	2 1/4	1 7/16	1.660	1 15/32	2 1/8
1	1 25/32	3 5/16	2 1/8	2 1/2	1 5/8	1.877	1 21/32	2 1/4
1 1/8	1 31/32	3 11/16	2 3/8	2 3/4	1 13/16	2.093	1 27/32	2 1/2
1 1/4	2 3/16	4 1/8	2 1/2	3	2	2.310	2 1/32	2 3/4
1 3/8	2 13/32	4 7/16	2 3/4	3 1/4	2 3/16	2.527	2 7/32	3
1 1/2	2 5/8	4 13/16	3	3 1/2	2 3/8	2.743	2 13/32	3 5/16
1 5/8	2 13/16	5 3/16	3 1/4	3 3/4	2 9/16	2.960		
1 3/4	3 1/32	5 9/16	3 1/2	4	2 3/4	3.176		
1 7/8	3 1/4	6 1/32	3 5/8	4 1/4	2 15/16	3.393		
2	3 15/32	6 1/8	3 7/8	4 1/2	3 1/8	3.609		
2 1/4	3 7/8	7 1/8	4 1/2	4 3/4	3 1/2	4.043		
2 1/2	4 5/16	7 15/16	5	5	3 7/8	4.476		
2 3/4	4 23/32	8 11/16	5 1/4	...	4 1/4	4.909		
3	5 5/32	9 1/2	5 3/4	...	4 5/8	5.342		
3 1/4	5 19/32	10 1/4	6 1/4	...	5	5.775		
3 1/2	6	11 1/16	6 1/2	...	5 3/8	6.208		
3 3/4	6 13/32	11 13/16	7	...	5 3/4	6.641		
4	6 7/8	12 9/16	7 1/2	...	6 1/8	7.074		
4 1/4	7 9/32	13 3/8	8	...	6 1/2	7.508		
4 1/2	7 23/32	14 3/16	8 1/2	...	6 7/8	7.941		
4 3/4	8 1/8	14 15/16	8 3/4	...	7 1/4	8.374		
5	8 9/16	15 3/4	9 1/2	...	7 5/8	8.807		
5 1/4	9	16 1/2	9 3/4	...	8	9.240		
5 1/2	9 13/32	17 1/4	10 1/4	...	8 3/8	9.673		
5 3/4	9 27/32	18 1/16	10 3/4	...	8 3/4	10.106		
6	10 13/16	18 13/16	11	...	9 1/8	10.539		

Hole in washer = diameter of bolt + 1/16 for bolts up to and including 1 inch in diameter.

Hole in washer = diameter of bolts + ⅛ inch for bolts 1⅛ to 2½ inches in diameter, inclusive.

TABLE 14.—COUNTERBORES WITH INSERTED PILOTS



⅜ to 1" Counterbores to have 4 Flutes
1" to 1½" " " " 6 "

Diam. A	K	L	M	N	O
3/8	1 7/32	1/4	1 15/32	3/16	From 3/16" to 15/32" in 32nds.
7/16	"	"	"	"	
1/2	"	"	"	"	
9/16	1 27/32	3/8	2 7/32	5/16	
5/8	"	"	"	"	From 1/2" to 31/32" in 32nds.
11/16	"	"	"	"	
3/4	"	"	"	"	
13/16	"	"	"	"	
7/8	"	"	"	"	
15/16	"	"	"	"	
1	"	"	"	"	
1 1/16	2 11/32	1/2	2 27/32	1/2	
1 1/8	"	"	"	"	
1 3/16	"	"	"	"	
1 1/4	"	"	"	"	From 1" to 1 15/32" in 32nds.
1 5/16	"	"	"	"	
1 3/8	"	"	"	"	
1 7/16	"	"	"	"	
1 1/2	"	"	"	"	

Diam. A	B	C	D	E	F	G	H	I	J
3/8	3/16	11/32	5/16	1	1 1/2	3 1/2	3/16	1 1/16	1 1/4
7/16	"	13/32	"	1 1/32	1 9/16	3 11/16	"	1 3/32	"
1/2	"	15/32	"	1 1/16	1 5/8	3 7/8	"	1 1/8	"
9/16	5/16	17/32	1/2	1 1/8	1 11/16	4 1/8	1/4	1 5/32	1 7/8
5/8	"	19/32	"	1 3/16	1 3/4	4 5/16	"	1 3/16	"
11/16	"	21/32	"	1 1/4	1 13/16	4 1/2	"	1 7/32	"
3/4	"	23/32	"	1 5/16	1 7/8	4 11/16	"	1 1/4	"
13/16	"	25/32	"	1 3/8	1 15/16	4 15/16	"	1 9/32	"
7/8	"	27/32	"	1 7/16	2	5 1/8	"	1 5/16	"
15/16	"	29/32	"	1 1/2	2 1/16	5 3/8	"	1 11/32	"
1	"	15/16	"	1 9/16	2 1/8	5 9/16	"	1 3/8	"
1 1/16	1/2	1	3/4	1 5/8	2 3/16	5 13/16	5/16	1 13/32	2 3/8
1 1/8	"	1 1/16	"	1 11/16	2 1/4	6	"	1 7/16	"
1 3/16	"	1 1/16	"	1 3/4	2 5/16	6 1/4	"	1 15/32	"
1 1/4	"	1 1/8	"	1 13/16	2 3/8	6 7/16	"	1 1/2	"
1 5/16	"	1 1/8	"	1 7/8	2 7/16	6 5/8	"	1 17/32	"
1 3/8	"	1 1/4	"	1 15/16	2 1/2	6 7/8	"	1 9/16	"
1 7/16	"	1 1/4	"	2	2 9/16	7 1/16	"	1 19/32	"
1 1/2	"	1 3/8	"	2 1/16	2 5/8	7 5/16		1 5/8	

BOWER ROLLER BEARING TOLERANCES AND FITTING PRACTICES

Proper fitting practice depends on the installation since deviations from normal are often necessary. These may be due to the type of service, ease of assembly and disassembly, hardness or finish of shaft and housing, hollow or solid shaft, load, speed, etc.

To some extent the type of bearing controls the fitting practice, that is, the rolling clearance in the straight roller bearing would be affected by the fit, whereas the clearance in the tapered roller bearing is adjustable.

Whichever race is stationary of the self-contained straight roller bearing type should have endwise movement to align itself with the rotating race. For the other types, the stationary race should be fixed.

In the column of fits, T means tight and L means loose. (Table 12.)

INTEGRAL RIGHT-ANGLED TRIANGLES

The erection of a perpendicular by the construction of a triangle whose sides are respectively 3, 4, and 5 units in length is a familiar and handy device. The following table gives a greater range of choice in the shape or proportions of the triangle employed. The table is a list of all integral, or whole-number, right-angled triangles the units of whose least sides do not exceed 20.

Height	Base	Hypotenuse	Height	Base	Hypotenuse	Height	Base	Hypotenuse
3	4	5	12	16	20	17	144	145
5	12	13	12	35	37	18	24	30
6	8	10	13	84	85	18	80	82
7	24	25	14	48	50	19	180	181
8	15	17	15	20	25	20	21	29
9	12	15	15	36	39	20	48	52
9	40	41	15	112	113	20	99	101
10	24	26	16	30	34			
11	60	61	16	63	65			

TABLE OF CHORDS

To construct any angle from the table of chords, page 843: Let the required angle be 36 degrees 38 minutes; the nearest angles in the table are 36 degrees 30 minutes and 36 degrees 40 minutes, and the chords are respectively 0.6263 and 0.6291, the difference 0.0028 corresponding to an angular difference of 10 minutes. To find the amount which must be added to 0.6263 (the chord corresponding to 36 degrees 30 minutes) in order to obtain the chord for a 36 degrees 38 minutes arc, multiply 0.0028 by $\frac{8}{10} = 0.00224$. $0.6263 + 0.00224 = 0.62854$. Then, if the radius is 1 inch and the angle 36 degrees 38 minutes, the chord will be 0.62854 inch.

TABLE 15.—TABLE OF CHORDS

THE TABULATED QUANTITIES = TWICE THE SINE OF HALF THE ARC

Deg.	0′	10′	20′	30′	40′	50′	60′
0	.0000	.0029	.0058	.0087	.0116	.0145	.0174
1	.0174	.0204	.0233	.0262	.0291	.0320	.0349
2	.0349	.0378	.0407	.0436	.0465	.0494	.0523
3	.0523	.0553	.0582	.0611	.0640	.0669	.0698
4	.0698	.0727	.0756	.0785	.0814	.0843	.0872
5	.0872	.0901	.0930	.0959	.0988	.1017	.1047
6	.1047	.1076	.1105	.1134	.1163	.1192	.1221
7	.1221	.1250	.1279	.1305	.1337	.1366	.1395
8	.1395	.1424	.1453	.1482	.1511	.1540	.1569
9	.1569	.1598	.1627	.1656	.1685	.1714	.1743
10	.1743	.1772	.1801	.1830	.1859	.1888	.1917
11	.1917	.1946	.1975	.2004	.2033	.2062	.2090
12	.2090	.2119	.2148	.2177	.2206	.2235	.2264
13	.2264	.2293	.2322	.2351	.2380	.2409	.2437
14	.2437	.2466	.2495	.2524	.2553	.2582	.2610
15	.2610	.2639	.2668	.2697	.2726	.2755	.2783
16	.2783	.2812	.2841	.2870	.2899	.2927	.2956
17	.2956	.2985	.3014	.3042	.3071	.3100	.3129
18	.3129	.3157	.3186	.3215	.3243	.3272	.3301
19	.3301	.3330	.3358	.3387	.3416	.3444	.3473
20	.3473	.3502	.3530	.3559	.3587	.3616	.3645
21	.3645	.3673	.3702	.3730	.3759	.3788	.3816
22	.3816	.3845	.3873	.3902	.3930	.3959	.3987
23	.3987	.4016	.4044	.4073	.4101	.4130	.4158
24	.4158	.4187	.4215	.4243	.4272	.4300	.4329
25	.4329	.4357	.4385	.4414	.4442	.4471	.4499
26	.4499	.4527	.4556	.4584	.4612	.4641	.4669
27	.4669	.4697	.4725	.4754	.4782	.4810	.4838
28	.4838	.4867	.4895	.4923	.4951	.4979	.5008
29	.5008	.5036	.5064	.5092	.5120	.5148	.5176
30	.5176	.5204	.5232	.5261	.5289	.5317	.5345
31	.5345	.5373	.5401	.5429	.5457	.5485	.5513
32	.5513	.5541	.5569	.5596	.5624	.5652	.5680
33	.5680	.5708	.5736	.5764	.5792	.5820	.5847
34	.5847	.5875	.5903	.5931	.5959	.5986	.6014
35	.6014	.6042	.6069	.6097	.6125	.6153	.6180
36	.6180	.6208	.6236	.6263	.6291	.6318	.6346
37	.6346	.6374	.6401	.6429	.6456	.6484	.6511
38	.6511	.6539	.6566	.6594	.6621	.6649	.6676
39	.6676	.6703	.6731	.6758	.6786	.6813	.6840
40	.6840	.6868	.6895	.6922	.6950	.6977	.7004
41	.7004	.7031	.7059	.7086	.7113	.7140	.7167
42	.7167	.7194	.7222	.7249	.7276	.7303	.7330
43	.7330	.7357	.7384	.7411	.7438	.7465	.7492
44	.7492	.7519	.7546	.7573	.7600	.7627	.7654
45	.7654	.7680	.7707	.7734	.7761	.7788	.7815

TABLE 15.—TABLE OF CHORDS—*Continued*

THE TABULATED QUANTITIES = TWICE THE SINE OF HALF THE ARC

Deg.	0′	10′	20′	30′	40′	50′	60′
46	.7815	.7841	.7868	.7895	.7921	.7948	.7975
47	.7975	.8001	.8028	.8055	.8081	.8108	.8135
48	.8135	.8161	.8188	.8214	.8241	.8267	.8294
49	.8294	.8320	.8347	.8373	.8400	.8426	.8452
50	.8452	.8479	.8505	.8531	.8558	.8584	.8610
51	.8610	.8636	.8663	.8689	.8715	.8741	.8767
52	.8767	.8793	.8820	.8846	.8872	.8898	.8924
53	.8924	.8950	.8976	.9002	.9028	.9054	.9080
54	.9080	.9106	.9132	.9157	.9183	.9209	.9235
55	.9235	.9261	.9286	.9312	.9338	.9364	.9389
56	.9389	.9415	.9441	.9466	.9492	.9518	.9543
57	.9543	.9569	.9594	.9620	.9645	.9671	.9696
58	.9696	.9722	.9747	.9772	.9798	.9823	.9848
59	.9848	.9874	.9899	.9924	.9949	.9975	1.0000
60	1.0000	1.0025	1.0050	1.0075	1.0100	1.0126	1.0151
61	1.0151	1.0176	1.0201	1.0226	1.0251	1.0276	.0301
62	1.0301	1.0326	1.0350	1.0375	1.0400	1.0425	1.0450
63	1.0450	1.0475	1.0500	1.0524	1.0550	1.0574	1.0598
64	1.0598	1.0623	1.0648	1.0672	1.0697	1.0721	1.0746
65	1.0746	1.0770	1.0795	1.0819	1.0844	1.0868	1.0893
66	1.0893	1.0917	1.0941	1.0966	1.0990	1.1014	1.1039
67	1.1039	1.1063	1.1087	1.1111	1.1135	1.1159	1.1184
68	1.1184	1.1208	1.1232	1.1256	1.1280	1.1304	1.1328
69	1.1328	1.1352	1.1376	1.1400	1.1424	1.1448	1.1471
70	1.1471	1.1495	1.1519	1.1543	1.1567	1.1590	1.1614
71	1.1614	1.1638	1.1661	1.1685	1.1708	1.1732	1.1756
72	1.1756	1.1780	1.1803	1.1826	1.1850	1.1873	1.1896
73	1.1896	1.1920	1.1943	1.1966	1.1990	1.2013	1.2036
74	1.2036	1.2059	1.2083	1.2106	1.2129	1.2152	1.2175
75	1.2175	1.2198	1.2221	1.2244	1.2267	1.2290	1.2313
76	1.2313	1.2336	1.2360	1.2382	1.2405	1.2427	1.2450
77	1.2450	1.2473	1.2496	1.2518	1.2541	1.2564	1.2586
78	1.2586	1.2609	1.2631	1.2654	1.2677	1.2699	1.2721
79	1.2721	1.2744	1.2766	1.2789	1.2811	1.2833	1.2856
80	1.2856	1.2878	1.2900	1.2922	1.2945	1.2967	1.2989
81	1.2989	1.3011	1.3033	1.3055	1.3077	1.3099	1.3121
82	1.3121	1.3143	1.3165	1.3187	1.3209	1.3231	1.3252
83	1.3252	1.3274	1.3296	1.3318	1.3340	1.3361	1.3383
84	1.3383	1.3404	1.3426	1.3447	1.3469	1.3490	1.3512
85	1.3512	1.3533	1.3555	1.3576	1.3597	1.3619	1.3640
86	1.3640	1.3661	1.3682	1.3704	1.3725	1.3746	1.3767
87	1.3767	1.3788	1.3809	1.3830	1.3851	1.3872	1.3893
88	1.3893	1.3914	1.3935	1.3956	1.3977	1.3997	1.4018
89	1.4018	1.4039	1.4060	1.4080	1.4101	1.4121	1.4142
90	1.4142						

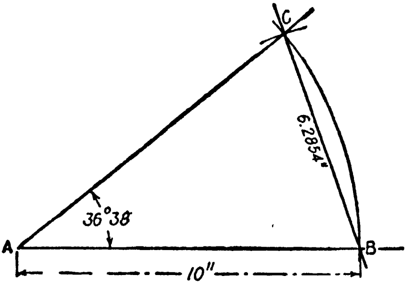
TABLE 16.—SPACING HOLES IN CIRCLES

No. of Divisions in Circle	Deg. of Arc	Length of Chord Dia. 1	Length of Chord Dia. 2	Length of Chord Dia. 3	Length of Chord Dia. 4	Length of Chord Dia. 5	Length of Chord Dia. 6
3	120	.866	1.732	2.598	3.464	4.330	5.196
4	90	.707	1.414	2.121	2.828	3.536	4.243
5	72	.588	1.176	1.763	2.351	2.938	3.527
6	60	.500	1.000	1.500	2.000	2.500	3.000
7	51°–25′	.434	.868	1.302	1.736	2.170	2.604
8	45	.383	.765	1.148	1.531	1.913	2.296
9	40	.342	.684	1.026	1.368	1.710	2.052
10	36	.309	.618	.927	1.236	1.545	1.854
11	32°–43′	.282	.564	.845	1.127	1.409	1.691
12	30	.259	.518	.776	1.035	1.294	1.553
13	27°–41′	.239	.479	.718	.958	1.197	1.436
14	25°–42′	.222	.445	.667	.890	1.112	1.334
15	24	.208	.416	.624	.832	1.040	1.247
16	22°–30′	.195	.390	.585	.780	.975	1.171
17	21°–11′	.184	.367	.551	.735	.918	1.102
18	20	.174	.347	.521	.695	.868	1.041
19	18°–57′	.164	.329	.493	.658	.822	.987
20	18	.156	.313	.468	.625	.782	.937
21	17°– 8′	.149	.298	.447	.596	.745	.894
22	16°–22′	.142	.286	.427	.569	.712	.855
23	15°–39′	.136	.273	.409	.545	.681	.818
24	15	.130	.261	.392	.522	.653	.783
25	14°–24′	.125	.251	.375	.501	.627	.752
26	13°–51′	.120	.241	.361	.482	.602	.723
27	13°–20′	.116	.232	.348	.464	.580	.697
28	12°–51′	.112	.224	.336	.448	.560	.672
29	12°–25′	.108	.216	.324	.432	.540	.648
30	12	.104	.209	.314	.418	.522	.627
31	11°–37′	.101	.202	.303	.404	.505	.606
32	11°–15′	.098	.196	.294	.393	.491	.589

TABLE 16.—SPACING HOLES IN CIRCLES—*Continued*

No. of Divisions in Circle	Deg. of Arc	Length of Chord Dia. 7	Length of Chord Dia. 8	Length of Chord Dia. 9	Length of Chord Dia. 10	Length of Chord Dia. 11	Length of Chord Dia. 12
3	120	6.062	6.928	7.794	8.660	9.526	10.392
4	90	4.950	5.657	6.364	7.071	7.778	8.485
5	72	4.115	4.702	5.290	5.878	6.465	7.053
6	60	3.500	4.000	4.500	5.000	5.500	6.000
7	51°–25′	3.037	3.471	3.905	4.339	4.773	5.207
8	45	2.679	3.061	3.444	3.827	4.210	4.592
9	40	2.394	2.736	3.078	3.420	3.762	4.104
10	36	2.163	2.472	2.781	3.090	3.399	3.708
11	32°–43′	1.973	2.254	2.536	2.818	3.100	3.381
12	30	1.812	2.069	2.329	2.588	2.847	3.106
13	27°–41′	1.676	1.915	2.154	2.394	2.633	2.873
14	25°–42′	1.557	1.779	2.000	2.224	2.446	2.669
15	24	1.455	1.663	1.871	2.079	2.287	2.495
16	22°–30′	1.366	1.561	1.756	1.951	2.146	2.341
17	21°–11′	1.286	1.469	1.653	1.837	2.020	2.204
18	20	1.216	1.389	1.563	1.737	1.910	2.084
19	18°–57′	1.151	1.316	1.480	1.645	1.809	1.974
20	18	1.095	1.251	1.408	1.564	1.721	1.877
21	17°– 8′	1.043	1.192	1.341	1.489	1.639	1.788
22	16°–22′	.996	1.139	1.281	1.423	1.566	1.708
23	15°–39′	.954	1.092	1.227	1.363	1.499	1.635
24	15	.914	1.044	1.175	1.305	1.436	1.566
25	14°–24′	.877	1.003	1.128	1.253	1.379	1.504
26	13°–51′	.843	.963	1.084	1.204	1.325	1.445
27	13°–20′	.813	.929	1.045	1.161	1.277	1.393
28	12°–51′	.784	.896	1.008	1.121	1.233	1.345
29	12°–25′	.756	.864	.972	1.080	1.188	1.296
30	12	.732	.836	.941	1.045	1.150	1.254
31	11°–37′	.707	.808	.910	1.011	1.112	1.213
32	11°–15′	.687	.785	.883	.982	1.080	1.178

In laying out an angle, as in the accompanying illustration, a base line *AB* can be drawn, say 10 inches long; then with a radius *AB* and center *A*, arc *BC* can be struck. Multiply chord 0.62854 inch by 10 giving 6.2854 inches, as the radius of an arc to be struck from center *B* and cutting arc *BC* at *C*. Through point *C* draw a line *AC* and the angle *BAC* will equal 36 degrees 38 minutes.



Where the angle required is in even degrees or sixths of degrees (as 10 minutes, 20 minutes, etc.), the corresponding chord may be taken directly from the table. A 10:1 layout is particularly convenient as the multiplication of the tabulated chords by 10 is readily performed mentally.

TABLE FOR SPACING HOLES IN CIRCLES

The table on page 845 will be found of service when it is desired to space any number of holes up to and including 32, in a circle. The number of divisions or holes desired will be found in the first column, the corresponding angle included at the center being given as a convenience in the second column. The remaining column heads cover various diameters of circles from 1 to 12 inches, and under these different heads and opposite the required number of holes will be found the lengths of chords or distances between hole centers for the given circle diameter.

Thus, if it is required to space off 18 holes in an 8-inch circle, by following down the first column until 18 is reached and then reading directly to the right, in the column headed "Length of Chord-Dia. 8," will be found the distance 1.389 as the chord length for that number of divisions and diameter of circle. Or, suppose a circle of 12 inches diameter is to be spaced off for a series of 27 holes to be drilled at equal distances apart: Opposite 27 found in the first column, and under the heading, "Dia. 12," will be found the chord 1.393 as the length to which the dividers may be set directly for laying off the series of holes.

If it is desired to lay off a series of holes in a circle of some diameter not given in the table, say 10 holes in an 11½-inch circle, subtract the chord for 10 holes in an 11-inch circle, or, 3.399 from the chord in the "Dia. 12" column, or 3.708, and add half the difference (0.154) to 3.399, giving 3.553 as the chord or center distance between holes. Or, if 24 holes are to be equally spaced in a 20-inch circle, all that is necessary in order to find the chord, or center distance, is to find opposite 24, and in the column headed, "Dia. 10," the quantity 1.305 and multiply this by 2, giving a length of 2.610 inches as the center distance.

TABLE OF SIDES, ANGLES, AND SINES

The table on page 849 is carried out for a much higher number of sides or spaces than are included in the preceding table and will be found useful in many cases not covered by that table. It was originally computed for finding the thicknesses of commutator bars and also for calculating the chord for spacing slots in armature punchings. In using this table, the diameter of the circle is, of course, multiplied by the sine opposite the desired number of holes or sides.

Assuming for illustration that a series of 51 holes are to be equally spaced about a circle having a diameter of 17 inches, opposite 51 in the column headed "No. of Sides," find the quantity 0.06156 in the column headed "Sine," and multiply this quantity by 17. The product 1.0465 is the length of the chord or the required distance between centers of the holes for this circle. Or, if 40 equidistant points are to be spaced about a circle 16 inches diameter, opposite the number of sides, 40, will be found the quantity 0.078459 which multiplied by 16 gives 1.255 inches as the distance between centers.

Table 17.—Sides, Angles, and Sines
Multiply Diameter by Sine to Get Length of Side
(Angle given is half of angle subtended at center)

No. Sides	Angle Deg. Min. Sec.	Sine	No. Sides	Angle Deg. Min. Sec.	Sine
3	60	.8660254	52	3-27-41.53	.0603784
4	45	.7071067	53	3-23-46.41	.0592405
5	36	.5877852	54	3-20	.0581448
6	30	.5000000	55	3-16-21.81	.0570887
7	25-42-51.42	.4338828	56	3-12-51.42	.0560704
8	22-30	.3826834	57	3- 9-28.42	.0550877
9	20-	.3420201	58	3- 6-12.41	.0541388
10	18-	.3090170	59	3- 3- 3.05	.0532221
11	16-21-49.09	.2817325	60	3-	.0523360
12	15-	.2588190	61	2-57- 2.95	.0514787
13	13-50-46.15	.2393157	62	2-54-11.61	.0506491
14	12-51-25.71	.2225208	63	2-51-25.71	.0498458
15	12	.2079116	64	2-48- 45	.0490676
16	11-15	.1950903	65	2-46- 9.23	.0483133
17	10-35-17.64	.1837495	66	2-43-38.18	.0475819
18	10-	.1736481	67	2-41-11.64	.0468722
19	9-28-25.26	.1645945	68	2-38-49.41	.0461834
20	9-	.1564344	69	2-36-31.30	.0455145
21	8-34-17.14	.1490422	70	2-34-17.14	.0448648
22	8-10-54.54	.1423148	71	2-32- 6.76	.0442333
23	7-49-33.91	.1361666	72	2-30	.0436194
24	7-30-	.1305262	73	2-27-56.71	.0430222
25	7-12-	.1253332	74	2-25-56.75	.0424411
26	6-55-23.07	.1205366	75	2-24-	.0418757
27	6-40	.1160929	76	2-22- 6.31	.0413249
28	6-25-42.85	.1119644	77	2-20-15.58	.0407885
29	6-12-24.82	.1081189	78	2-18-27.69	.0402659
30	6-	.1045284	79	2-16-42.53	.0397565
31	5-48-23.22	.1011683	80	2-15-	.0392598
32	5-37-30	.0980171	81	2-13-20	.0387753
33	5-27-16.36	.0950560	82	2-11-42.45	.0383027
34	5-17-38.82	.0922683	83	2-10- 7.22	.0378414
35	5- 8-34.28	.0896392	84	2- 8-34.28	.0373911
36	5-	.0871557	85	2- 7- 3.54	.0369515
37	4-51-53.51	.0848058	86	2- 5-34.88	.0365220
38	4-44-12.63	.0825793	87	2- 4- 8.27	.0361023
39	4-36-55.38	.0804665	88	2- 2-43.63	.0356923
40	4-30-	.0784591	89	2- 1-20.89	.0352914
41	4-23-24.87	.0765492	90	2-	.0348995
42	4-17- 8.57	.0747301	91	1-58-40.87	.0345160
43	4-11- 9.76	.0729952	92	1-57-23.47	.0341410
44	4- 5-27.27	.0713391	93	1-56- 7.74	.0337741
45	4	.0697565	94	1-54-53.61	.0334149
46	3-54-46.95	.0682423	95	1-53-41.05	.0330633
47	3-49-47.23	.0667926	96	1-52-30.	.0327190
48	3-45-	.0654031	97	1-51-20.41	.0323818
49	3-40-24.49	.0640702	98	1-50-12.24	.0320515
50	3-36-	.0627905	99	1-49- 5.45	.0317279
51	3-31-45.88	.0615609	100	1-48-	.0314107

TABLE 17.—SIDES, ANGLES, AND SINES—*Continued*
Multiply Diameter by Sine to Get Length of Side
(Angle given is half of angle subtended at center)

No. Sides	Angle Deg. Min. Sec.	Sine	No. Sides	Angle Deg. Min. Sec.	Sine
101	1–46–55.84	.0310998	151	1–11–31.39	.0208037
102	1–45–52.94	.0307950	152	1–11– 3.15	.0206668
103	1–44–51.26	.0304961	153	1–10–35.29	.0205318
104	1–43–50.76	.0302029	154	1–10– 7.79	.0203985
105	1–42–51.42	.0299154	155	1– 9–40.64	.0202669
106	1–41–53.20	.0296332	156	1– 9–13.84	.0201370
107	1–40–56.07	.0293564	157	1– 8–47.38	.0200087
108	1–40–	.0290847	158	1– 8–21.26	.0198821
109	1–39– 4.95	.0288179	159	1– 7–55.47	.0197571
110	1–38–10.90	.0285560	160	1– 7–30	.0196336
111	1–37–17.83	.0282488	161	1– 7– 4.84	.0195117
112	1–36–25.71	.0280462	162	1– 6–40	.0193913
113	1–35–34.51	.0277981	163	1– 6–15.46	.0192723
114	1–34–44.21	.0275543	164	1– 5–51.21	.0191548
115	1–33–54.78	.0273147	165	1– 5–27.27	.0190387
116	1–33– 6.20	.0270793	166	1– 5– 3.61	.0189241
117	1–32–18.46	.0268479	167	1– 4–40.23	.0188107
118	1–31–31.52	.0266204	168	1– 4–17.14	.0186988
119	1–30–45.38	.0263968	169	1– 3–54.31	.0185881
120	1–30–	.0261769	170	1– 3–31.76	.0184788
121	1–29–15.37	.0259606	171	1– 3– 9.47	.0183708
122	1–28–31.47	.0257478	172	1– 2–47.44	.0182640
123	1–27–48.29	.0255386	173	1– 2–25.66	.0181584
124	1–27– 5.80	.0253326	174	1– 2– 4.13	.0180541
125	1–26–24	.0251300	175	1– 1–42.85	.0179509
126	1–25–42.85	.0249306	176	1– 1–21.81	.0178489
127	1–25– 2.36	.0247344	177	1– 1– 1.01	.0177481
128	1–24–22.50	.0245412	178	1– 0–40.44	.0176484
129	1–23–43.25	.0243509	179	1– 0–20.11	.0175498
130	1–23– 4.61	.0241637	180	1– –	.0174524
131	1–22–26.56	.0239793	181	–59–40.11	.0173559
132	1–21–49.09	.0237976	182	–59–20.43	.0172605
133	1–21–12.18	.0236188	183	–59– 0.98	.0171663
134	1–20–35.82	.0234425	184	–58–41.73	.0170730
135	1–20–	.0232689	185	–58–22.70	.0169807
136	1–19–24.70	.0230978	186	–58– 3.87	.0168894
137	1–18–49.92	.0229292	187	–57–45.24	.0167991
138	1–18–15.65	.0227631	188	–57–26.30	.0167097
139	1–17–41.87	.0225994	189	–57– 8.57	.0166214
140	1–17– 8.57	.0224380	190	–56–50.52	.0165339
141	1–16–35.74	.0222789	191	–56–32.67	.0164473
142	1–16– 3.38	.0221220	192	–56–15	.0163617
143	1–15–31.46	.0219673	193	–55–57.51	.0162769
144	1–15–	.0218148	194	–55–40.20	.0161930
145	1–14–28.96	.0216644	195	–55–23.07	.0161100
146	1–13–58.35	.0215160	196	–55– 6.12	.0160278
147	1–13–28.16	.0213697	197	–54–49.34	.0159464
148	1–12–58.37	.0212253	198	–54–32.72	.0158659
149	1–12–28.99	.0210829	199	–54–16.28	.0157862
150	1–12–	.0209424	200	–54–	0157073

TABLE 17.—SIDES, ANGLES, AND SINES—*Continued*
Multiply Diameter by Sine to Get Length of Side
(Angle given is half of angle subtended at center)

No. Sides	Angle Min. Sec.	Sine	No. Sides	Angle Min. Sec.	Sine
201	53–43.88	.0156244	251	43– 1.67	.0125160
202	53–27.92	.0155518	252	42–51.43	.0124663
203	53–12.12	.0154752	253	42–41.26	.0124171
204	52–56.47	.0153993	254	42–31.18	.0123682
205	52–40.97	.0153242	255	42–21.18	.0123197
206	52–25.63	.0152498	256	42–11.25	.0122715
207	52–10.44	.0151764	257	42– 1.40	.0122238
208	51–55.38	.0151033	258	41–51.63	.0121764
209	51–40.48	.0150310	259	41–41.93	.0121294
210	51–25.71	.0149595	260	41–32.31	.0120827
211	51–11.09	.0148886	261	41–22.76	.0120364
212	50–56.60	.0148183	262	41–13.28	.0119905
213	50–42.25	.0147487	263	41– 3.88	.0119449
214	50–28.04	.0146798	264	40–54.54	.0118997
215	50–13.96	.0146115	265	40–45.28	.0118548
216	50–	.0145439	266	40–36.09	.0118102
217	49–46.17	.0144769	267	40–26.96	.0117660
218	49–32.48	.0144104	268	40–17.91	.0117221
219	49–18.91	.0143446	269	40– 8.93	.0116786
220	49– 5.46	.0142794	270	40–	.0116353
221	48–52.13	.0142148	271	39–51.14	.0115923
222	48–38.92	.0141508	272	39–42.35	.0115497
223	48–25.83	.0140874	273	39–33.63	.0115074
224	48–12.86	.0140245	274	39–24.96	.0114654
225	48–	.0139622	275	39–16.36	.0114237
226	47–47.26	.0139004	276	39– 7.83	.0113823
227	47–34.63	.0138392	277	38–59.35	.0113412
228	47–22.11	.0137785	278	38–50.94	.0113004
229	47– 9.69	.0137183	279	38–42.58	.0112599
230	46–57.39	.0136587	280	38–34.28	.0112197
231	46–45.19	.0135995	281	38–26.05	.0111798
232	46–33.10	.0135409	282	38–17.87	.0111401
233	46–21.11	.0134828	283	38– 9.75	.0111008
234	46– 9.23	.0134252	284	38– 1.69	.0110617
235	45–57.45	.0133681	285	37–53.68	.0110229
236	45–45.76	.0133115	286	17–45.73	.0109844
237	45–34.18	.0132553	287	37–37.84	.0109461
238	45–22.69	.0131996	288	37–30	.0109081
239	45–11.29	.0131444	289	37–22.21	.0108704
240	45–	.0130896	290	37–14.48	.0108329
241	44–48.80	.0130353	291	37– 6.80	.0107957
242	44–37.68	.0129814	292	36–59.18	.0107587
243	44–26.67	.0129280	293	36–51.60	.0107220
244	44–15.74	.0128750	294	36–44.08	.0106855
245	44– 4.90	.0128225	295	36–36.61	.0106493
246	43–54.15	.0127704	296	36–29.19	.0106133
247	43–43.48	.0127187	297	36–21.82	.0105776
248	43–32.40	.0126674	298	36–14.50	.0105421
249	43–22.41	.0126165	299	36– 7.22	.0105068
250	43–12	.0125661	300	36–	.0104718

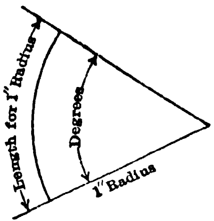
TABLE 17.—SIDES, ANGLES, AND SINES—*Continued*
Multiply Diameter by Sine to Get Length of Side
(Angle given is half of angle subtended at center)

No. Sides	Angle Min. Sec.	Sine	No. Sides	Angle Min. Sec.	Sine
301	35-52.82	.0104370	351	30-46.15	.0089502
302	35-45.69	.0104024	352	30-40.91	.0089248
303	35-38.61	.0103681	353	30-35.69	.0088996
304	35-31.58	.0103340	354	30-30.51	.0088744
305	35-24.59	.0103001	355	30-25.35	.0088494
306	35-17.65	.0102665	356	30-20.22	.0088245
307	35-10.75	.0102330	357	30-15.12	.0087998
308	35- 3.90	.0101998	358	30-10.05	.0087753
309	34-57.09	.0101668	359	30- 5.01	.0087508
310	34-50.32	.0101340	360	30-	.0087265
311	34-43.60	.0101014	361	29-55.01	.0087023
312	34-36.92	.0100690	362	29-50.05	.0086783
313	34-30.29	.0100368	363	29-45.12	.0086544
314	34-23.69	.0100049	364	29-40.22	.0086306
315	34-17.14	.0099731	365	29-35.34	.0086070
316	34-10.63	.0099415	366	29-30.49	.0085835
317	34- 4.16	.0099102	367	29-25.67	.0085601
318	33-57.74	.0098791	368	29-20.87	.0085368
319	33-51.35	.0098482	369	29-16.10	.0085137
320	33-45	.0098174	370	29-11.35	.0084907
321	33-38.69	.0097868	371	29- 6.63	.0084678
322	33-32.42	.0097564	372	29- 1.94	.0084451
323	33-26.19	.0097261	373	28-57.27	.0084224
324	33-20	.0096961	374	28-52.62	.0083999
325	33-13.85	.0096663	375	28-48	.0083775
326	33- 7.73	.0096367	376	28-43.40	.0083552
327	33- 1.65	.0096072	377	28-38.83	.0083331
328	32-55.61	.0095779	378	28-34.28	.0083110
329	32-49.60	.0095488	379	28-29.76	.0082891
330	32-43.64	.0095198	380	28-25.26	.0082673
331	32-37.70	.0094911	381	28-20.78	.0082456
332	32-31.81	.0094625	382	28-16.33	.0082240
333	32-25.95	.0094341	383	28-11.91	.0082025
334	32-20.12	.0094059	384	28- 7.50	.0081812
335	32-14.33	.0093778	385	28- 3.12	.0081599
336	32- 8.57	.0093499	386	27-58.76	.0081387
337	32- 2.85	.0093221	387	27-54.42	.0081177
338	31-57.16	.0092945	388	27-50.10	.0080968
339	31-51.50	.0092671	389	27-45.81	.0080760
340	31-45.88	.0092398	390	27-41.54	.0080553
341	31-40.29	.0092127	391	27-37.29	.0080347
342	31-34.74	.0091858	392	27-33.06	.0080142
343	31-29.21	.0091590	393	27-28.85	.0079938
344	31-23.72	.0091324	394	27-24.67	.0079735
345	31-18.26	.0091059	395	27-20.51	.0079533
346	31-12.83	.0090796	396	27-16.36	.0079332
347	31- 7.44	.0090534	397	27-12.24	.0079132
348	31- 2.07	.0090274	398	27- 8.14	.0078934
349	30-56.73	.0090016	399	27- 4.06	.0078736
350	30-51.43	.0089758	400	27-	.0078534

TABLE 17.—SIDES, ANGLES, AND SINES—*Continued*
Multiply Diameter by Sine to Get Length of Side
(Angle given is half of angle subtended at center)

No. Sides	Angle Min. Sec.	Sine	No. Sides	Angle Min. Sec.	Sine
401	26–55.96	.0078343	451	23–56.81	.0069658
402	26–51.94	.0078148	452	23–53.63	.0069504
403	26–47.94	.0077954	453	23–50.46	.0069351
404	26–43.96	.0077761	454	23–47.31	.0069198
405	26–40	.0077569	455	23–44.17	.0069046
406	26–36.06	.0077378	456	23–41.05	.0068894
407	26–32.14	.0077188	457	23–37.94	.0068744
408	26–28.23	.0076999	458	23–34.84	.0068594
409	26–24.35	.0076811	459	23–31.76	.0068444
410	26–20.49	.0076623	460	23–28.69	.0068295
411	26–16.64	.0076437	461	23–25.64	.0068147
412	26–12.82	.0076251	462	23–22.60	.0067999
413	26– 9.01	.0076067	463	23–19.57	.0067852
414	26– 5.22	.0075883	464	23–16.55	.0067706
415	26– 1.45	.0075700	465	23–13.55	.0067561
416	25–57.70	.0075518	466	23–10.56	.0067416
417	25–53.96	.0075337	467	23– 7.58	.0067272
418	25–50.24	.0075157	468	23– 4.61	.0067128
419	25–46.54	.0074977	469	23– 1.66	.0066983
420	25–42.86	.0074799	470	22–58.72	.0066842
421	25–39.19	.0074621	471	22–55.79	.0066700
422	25–35.54	.0074444	472	22–52.88	.0066559
423	25–31.91	.0074268	473	22–49.98	.0066418
424	25–28.30	.0074093	474	22–47.09	.0066278
425	25–24.70	.0073919	475	22–44.21	.0066138
426	25–21.12	.0073745	476	22–41.34	.0065999
427	25–17.56	.0073573	477	22–38.49	.0065861
428	25–14.02	.0073401	478	22–35.65	.0065723
429	25–10.49	.0073230	479	22–32.82	.0065585
430	25– 6.98	.0073059	480	22–30	.0065449
431	25– 3.48	.0072890	481	22–27.20	.0065313
432	25–	.0072721	482	22–24.40	.0065178
433	24–56.54	.0072553	483	22–21.61	.0065043
434	24–53.09	.0072386	484	22–18.84	.0064909
435	24–49.66	.0072220	485	22–16.08	.0064775
436	24–46.24	.0072054	486	22–13.33	.0064641
437	24–42.84	.0071889	487	22–10.59	.0064509
438	24–39.45	.0071725	488	22– 7.87	.0064377
439	24–36.08	.0071562	489	22– 5.16	.0064245
440	24–32.73	.0071399	490	22– 2.45	.0064114
441	24–29.39	.0071237	491	21–59.75	.0063983
442	24–26.06	.0071076	492	21–57.07	.0063853
443	24–22.75	.0070916	493	21–54.40	.0063723
444	24–19.46	.0070756	494	21–51.74	.0063594
445	24–16.18	.0070597	495	21–49.09	.0063466
446	24–12.91	.0070439	496	21–46.45	.0063338
447	24– 9.66	.0070281	497	21–43.82	.0063211
448	24– 6.43	.0070124	498	21–41.20	.0063084
449	24– 3.21	.0069968	499	21–38.59	.0062957
450	24–	.0069813	500	21–36	.0062831

LENGTHS OF CIRCULAR ARCS



THE table gives the lengths of circular arcs to the radius of one, for angles from 1 to 180 degrees. The lengths for minutes of arcs are given at the right.

To find the length of a circular arc with radius of 1 inch and angle of 45 degrees 20 minutes. Opposite 45 degrees find 0.7854, and opposite 20 minutes 0.0058. Adding these gives 0.7912 inch as the length of arc. If the radius is 2 inches, multiply the lengths in the table by 2.

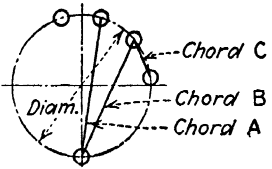
TABLE 18.—LENGTHS OF CIRCULAR ARCS TO RADIUS OF 1

Degree	Length	Degree	Length	Degree	Length	Degree	Length	Min.	Length	Min.	Length
0	0.0000	45	0.7854	90	1.5708	135	2.3562	0	0.0000	45	0.0131
1	0.0175	46	0.8029	91	1.5882	136	2.3736	1	0.0003	46	0.0134
2	0.0349	47	0.8203	92	1.6057	137	2.3911	2	0.0006	47	0.0137
3	0.0524	48	0.8378	93	1.6232	138	2.4086	3	0.0009	48	0.0140
4	0.0698	49	0.8552	94	1.6406	139	2.4260	4	0.0012	49	0.0143
5	0.0873	50	0.8728	95	1.6581	140	2.4435	5	0.0015	50	0.0145
6	0.1047	51	0.8901	96	1.6755	141	2.4609	6	0.0017	51	0.0148
7	0.1222	52	0.9076	97	1.6930	142	2.4784	7	0.0020	52	0.0151
8	0.1396	53	0.9250	98	1.7104	143	2.4958	8	0.0023	53	0.0154
9	0.1571	54	0.9425	99	1.7279	144	2.5133	9	0.0026	54	0.0157
10	0.1745	55	0.9599	100	1.7453	145	2.5307	10	0.0029	55	0.0160
11	0.1920	56	0.9774	101	1.7628	146	2.5482	11	0.0032	56	0.0163
12	0.2094	57	0.9948	102	1.7802	147	2.5656	12	0.0035	57	0.0166
13	0.2269	58	1.0123	103	1.7977	148	2.5831	13	0.0038	58	0.0169
14	0.2443	59	1.0297	104	1.8151	149	2.6005	14	0.0041	59	0.0172
15	0.2618	60	1.0472	105	1.8326	150	2.6180	15	0.0044	60	0.0175
16	0.2793	61	1.0647	106	1.8500	151	2.6354	16	0.0047		
17	0.2967	62	1.0821	107	1.8675	152	2.6529	17	0.0050		
18	0.3142	63	1.0996	108	1.8850	153	2.6704	18	0.0052		
19	0.3316	64	1.1170	109	1.9024	154	2.6878	19	0.0055		
20	0.3491	65	1.1345	110	1.9199	155	2.7052	20	0.0058		
21	0.3665	66	1.1519	111	1.9373	156	2.7227	21	0.0061		
22	0.3840	67	1.1694	112	1.9548	157	2.7402	22	0.0064		
23	0.4014	68	1.1868	113	1.9722	158	2.7576	23	0.0067		
24	0.4189	69	1.2043	114	1.9897	159	2.7751	24	0.0070		
25	0.4363	70	1.2217	115	2.0071	160	2.7925	25	0.0073		
26	0.4538	71	1.2392	116	2.0246	161	2.8100	26	0.0076		
27	0.4712	72	1.2566	117	2.0420	162	2.8274	27	0.0079		
28	0.4887	73	1.2741	118	2.0595	163	2.8449	28	0.0081		
29	0.5061	74	1.2915	119	2.0769	164	2.8623	29	0.0084		
30	0.5236	75	1.3090	120	2.0944	165	2.8798	30	0.0087		
31	0.5411	76	1.3265	121	2.1118	166	2.8972	31	0.0090		
32	0.5585	77	1.3439	122	2.1293	167	2.9147	32	0.0093		
33	0.5760	78	1.3614	123	2.1468	168	2.9322	33	0.0096		
34	0.5934	79	1.3788	124	2.1642	169	2.9496	34	0.0099		
35	0.6109	80	1.3963	125	2.1817	170	2.9671	35	0.0102		
36	0.6283	81	1.4137	126	2.1991	171	2.9845	36	0.0105		
37	0.6458	82	1.4312	127	2.2166	172	3.0020	37	0.0108		
38	0.6632	83	1.4486	128	2.2340	173	3.0194	38	0.0111		
39	0.6807	84	1.4661	129	2.2515	174	3.0369	39	0.0113		
40	0.6981	85	1.4835	130	2.2690	175	3.0543	40	0.0116		
41	0.7156	86	1.5010	131	2.2864	176	3.0718	41	0.0119		
42	0.7330	87	1.5184	132	2.3038	177	3.0892	42	0.0122		
43	0.7505	88	1.5359	133	2.3212	178	3.1067	43	0.0125		
44	0.7679	89	1.5533	134	2.3387	179	3.1241	44	0.0128		

CHORDAL DIMENSIONS

TABLE 19.—CHORDAL DIMENSIONS USED IN MULTIPLE SPINDLE HEADS

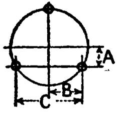
These dimensions were prepared by the makers of the Krueger multiple-spindle drilling heads to assist in laying out center distances of spindles.



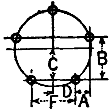
No. of Divisions	Chords, in inches		
	A	*B*	*C*
1	0.00000	0.00000	0.00000
2	1.00000	1.00000	1.00000
3	0.86603	0.86603	0.86603
4	1.00000	0.70710	0.70710
5	0.95106	0.58778	0.58778
6	1.00000	0.86603	0.50000
7	0.97493	0.78183	0.43388
8	1.00000	0.92388	0.38268
9	0.98481	0.86603	0.34202
10	1.00000	0.95105	0.30901
11	0.98982	0.90963	0.28173
12	1.00000	0.96592	0.25881
13	0.99271	0.93501	0.23931
14	1.00000	0.97492	0.22251
15	0.99452	0.95105	0.20791
16	1.00000	0.98078	0.19509
17	0.99573	0.96182	0.18374
18	1.00000	0.98480	0.17364
19	0.99658	0.96940	0.16459
20	1.00000	0.98768	0.15643
21	0.99720	0.97492	0.14904
22	1.00000	0.99010	0.14231
23	0.99766	0.97908	0.13616
24	1.00000	0.99144	0.13052
25	0.99803	0.98228	0.12533
26	1.00000	0.99270	0.12053
27	0.99831	0.98480	0.11609
28	1.00000	0.99371	0.11196
29	0.99853	0.98682	0.10811
30	1.00000	0.99452	0.10452
31	0.99871	0.98847	0.10116
32	1.00000	0.99518	0.09801
33	0.99886	0.98982	0.09505
34	1.00000	0.99573	0.09226
35	0.99899	0.99095	0.08963
36	1.00000	0.99619	0.08715
37	0.99910	0.99192	0.08480
38	1.00000	0.99658	0.08257
39	0.99918	0.99269	0.08046
40	1.00000	0.99691	0.07845
41	0.99926	0.99338	0.07654
42	1.00000	0.99720	0.07473
43	0.99933	0.99355	0.07299
44	1.00000	0.99745	0.07133
45	0.99939	0.99452	0.06975
46	1.00000	0.99766	0.06824
47	0.99944	0.99497	0.06679
48	1.00000	0.99785	0.06540
49	0.99948	0.99539	0.06406
50	1.00000	0.99802	0.06279

This table gives chordal dimensions for a diameter of 1 inch. For any other diameter, multiply the chord given in the table by the given diameter. In the diagram, *A* represents longest chord; *B*, second longest chord; and *C*, shortest chord. If N = number of divisions, then $A = \cos 90 \div N$ for odd numbers, and 1 for even numbers; $B = \cos 270 \div N$ for odd numbers and $\cos 180 \div N$ for even numbers; $C = \sin 180 \div N$.

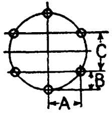
EXAMPLE.—A drill jig is to have 9 holes equally spaced on a 10-inch circle. $A = 0.98481 \times 10 = 9.8481$ inches; $B = 0.86603 \times 10 = 8.6603$ inches; and $C = 0.34202 \times 10 = 3.4202$ inches.



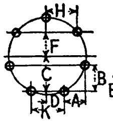
1



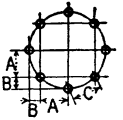
2



3



4



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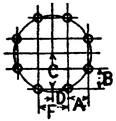

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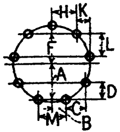
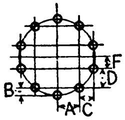


7



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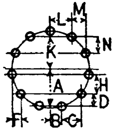
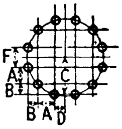


9



10

TABLE 20.—COORDINATES FOR THE JIG BORER*

Constants for Locating Holes Spaced around a Circle

Multiply Value Shown by Diameter of Circle Being Calculated

Number	No. of Hole	*A*	*B*	*C*	*D*	*F*	*H*	*K*	*L*	*M*	*N*
1	3	0.25000	0.43302	0.86603							
2	5	0.18164	0.55902	0.40451	0.29389	0.58779					
3	6	0.43302	0.25000	0.50000							
4	7	0.27052	0.33922	0.45049	0.21694	0.31175	0.39090	0.43388			
5	8	0.35355	0.14650	0.38268							
6	8	0.27059	0.27059	0.46194	0.19134	0.38268					
7	9	0.46985	0.17101	0.26200	0.21985	0.38302	0.32139	0.17101	0.29620	0.34202	
8	10	0.29389	0.09549	0.18164	0.25000	0.15451					
9	11	0.47975	0.14087	0.23701	0.15232	0.11704	0.25627	0.42063	0.27032	0.18449	0.21292
10	12	0.22415	0.12941	0.48297	0.12941	0.25882					

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* Paul Glaesmer.

AMERICAN DRAWING-ROOM PRACTICE

Third-angle projection is standard in American practice, the usual arrangement of views being as in Fig. 2. Conventional line symbols are shown in Fig. 3, whereas ends of broken pieces are seen in Fig. 4. Alternate positions of a moving part and connections to old work are as in Fig. 5. Figure 6 shows standard section linings.

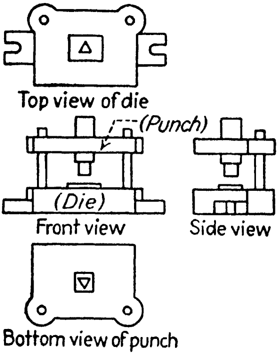


FIG. 2.—Third-Angle Projection

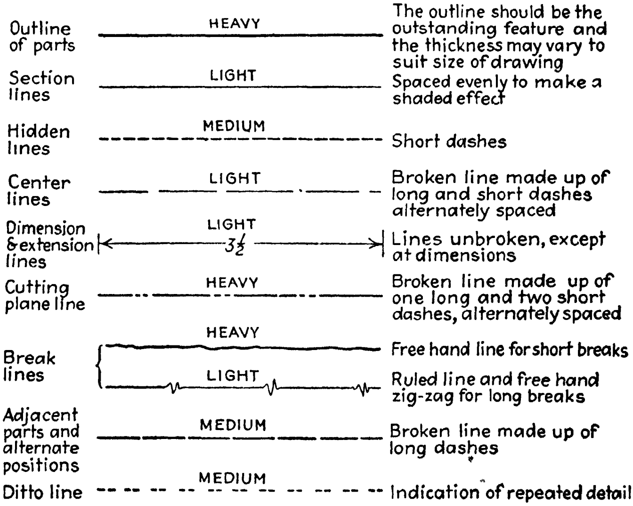

Outline of parts
HEAVY
The outline should be the outstanding feature and the thickness may vary to suit size of drawing
Section lines
LIGHT
Spaced evenly to make a shaded effect
Hidden lines
MEDIUM
Short dashes
Center lines
LIGHT
Broken line made up of long and short dashes alternately spaced
Dimension & extension lines
LIGHT
3½
Lines unbroken, except at dimensions
Cutting plane line
HEAVY
Broken line made up of one long and two short dashes, alternately spaced
Break lines
HEAVY
Free hand line for short breaks
LIGHT
Ruled line and free hand zig-zag for long breaks
Adjacent parts and alternate positions
MEDIUM
Broken line made up of long dashes
Ditto line
MEDIUM
Indication of repeated detail

FIG. 3.—Lines Used on Drawings

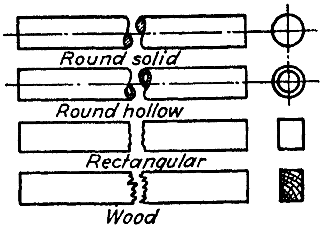


FIG. 4.—How Broken Pieces Are Shown

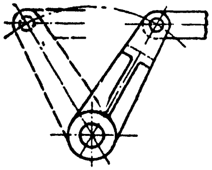


FIG. 5a.—Indicating Two Positions

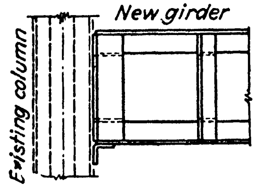


FIG. 5b.—Showing Old and New Parts

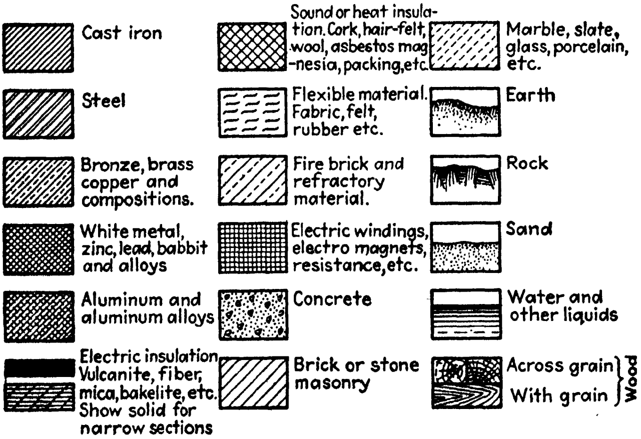

Cast iron
Steel
Bronze, brass copper and compositions.
White metal, zinc, lead, babbit and alloys
Aluminum and aluminum alloys
Electric insulation Vulcanite, fiber, mica, bakelite, etc. Show solid for narrow sections
Sound or heat insulation. Cork, hair-felt, wool, asbestos magnesia, packing, etc.
Flexible material. Fabric, felt, rubber etc.
Fire brick and refractory material.
Electric windings, electro magnets, resistance, etc.
Concrete
Brick or stone masonry
Marble, slate, glass, porcelain, etc.
Earth
Rock
Sand
Water and other liquids
Across grain
With grain
Wood

FIG. 6.—Standard Section Lining

Dimension lines, extension lines, and leaders are given in Fig. 7. General rules are:

Dimensions of parts that can be measured or that can be produced with sufficient accuracy by using an ordinary scale should be written in units and common fractions. Parts requiring greater accuracy should be dimensioned in decimal fractions.

Wire, tubing walls, sheet metal, standard structural sections, etc., should be described by commercial designation followed by dimension in decimals.

Dimensions up to and including 72 inches should preferably be expressed in inches; and those greater than this length, in feet and inches.

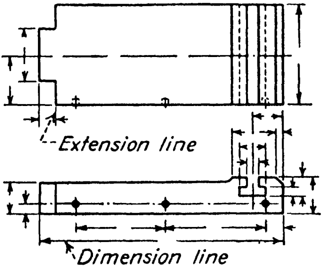


FIG. 7.—Dimension Lines on Drawings

Where dimensions call for accurate machining with small tolerances, it is recommended that the total dimension be given in inches and decimal fractions.

In structural drawing all dimensions of 12 inches and over should be expressed in feet and inches.

In automotive, locomotive, sheet metal, and some other practices all dimensions are specified in inches.

Tolerances are shown in two ways such as $8.625^{-0.000}_{+0.002}$ or 8.625-8.627.

Dimensioning Tapers

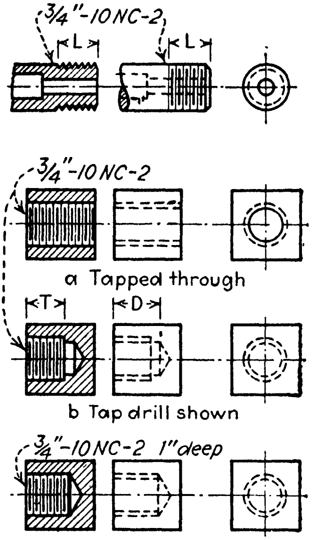
Tapers are usually given in the difference in diameter per foot of length, measured on the axis, not on the slope of the taper. Three methods of measurement are used.

Standard Tapers.—Give one diameter or width, the length, and insert note on drawing designating the taper by number taken from *American Standards Association Bulletin* B-5.

Special Tapers.—In dimensioning a taper when the slope is specified, the length and only one diameter should be given, or the diameters at both ends of the taper should be given, and length omitted.

Precision Work.—In certain cases where very precise measurements are necessary, the taper surface, either external or internal, is specified by giving a diameter at a certain distance from a surface and the slope of the taper.

Standard screw-thread representations are as shown in Figs. 8 and 9.

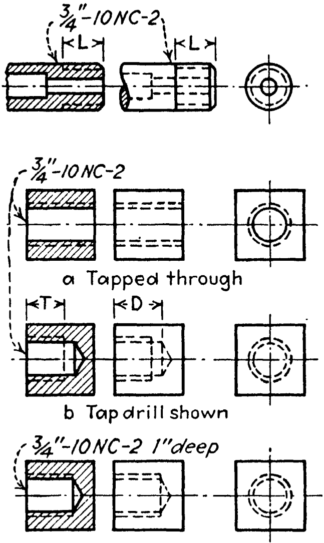


a Tapped through

b Tap drill shown

c Tap drill not shown

FIG. 8.—Thread Symbols—Regular



a Tapped through

b Tap drill shown

c Tap drill not shown

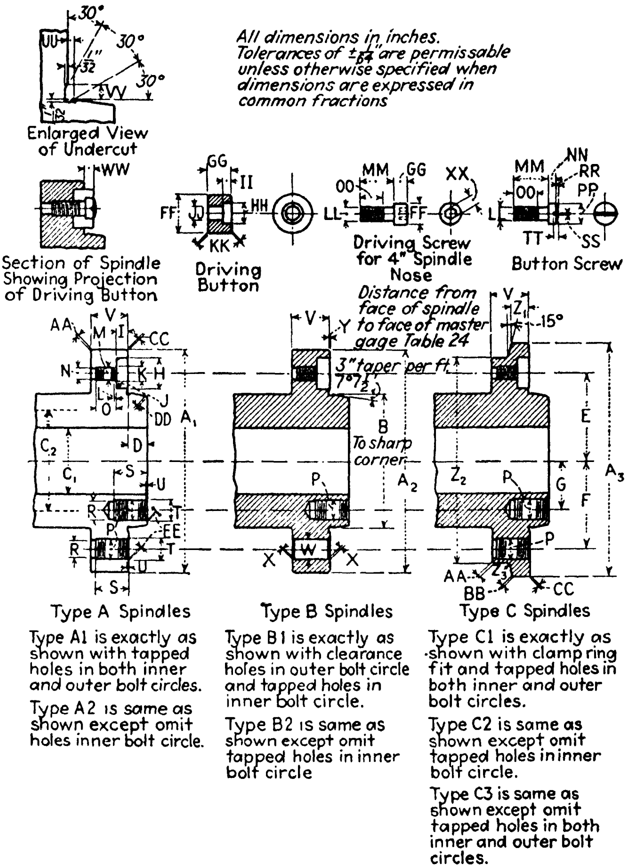
FIG. 9.—Thread Symbols—Simplified

STANDARD LATHE SPINDLE NOSES

There are four types of the American standard lathe spindle nose, adopted in 1936. See Tables 21 to 24. Type A1 has two rows of tapped holes and a driving button. Type A2 has only the outer circle tapped holes. Type B1 has clearance holes outside, inner for bolts or studs, and drive button. Type B2 has only the outer clearance holes. Type C1 is the same as A1 except that provision is made for a clamping ring. Type C2 is the same as A2 with the clamping ring added. Type C3 has a clamping ring but no holes in the flange. Type D1 has six equally spaced clearance holes and a series of cams for locking faceplate or chuck. Tables showing the important dimensions follow.

Standard spindles for A, B and C lathes are shown in Fig. 10, and the bolt layout for three sizes is given in Fig. 11.

Faceplates and chucks are located on the spindle by a short taper of 3 in. per foot and are held by bolts, capscrews or cams. Type A1 nose is recommended for turret lathes, although D1 is



All dimensions in inches. Tolerances of ±1/64" are permissable unless otherwise specified when dimensions are expressed in common fractions

Type A1 is exactly as shown with tapped holes in both inner and outer bolt circles.

Type A2 is same as shown except omit holes inner bolt circle.

Type B1 is exactly as shown with clearance holes in outer bolt circle and tapped holes in inner bolt circle.

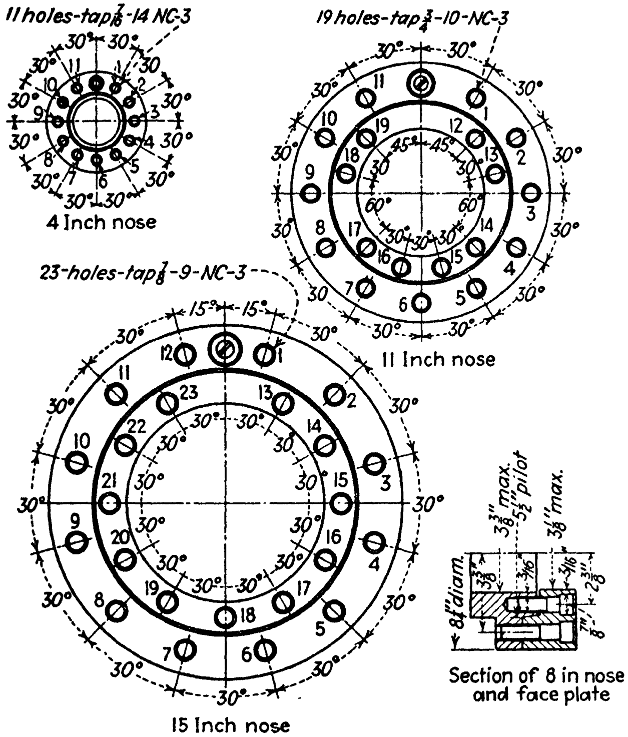
Type B2 is same as shown except omit tapped holes in inner bolt circle

Type C1 is exactly as shown with clamp ring fit and tapped holes in both inner and outer bolt circles.

Type C2 is same as shown except omit tapped holes in inner bolt circle.

Type C3 is same as shown except omit tapped holes in both inner and outer bolt circles.

FIG. 10.—Standard Spindles for A, B, and C Lathes



4 Inch nose

11 Inch nose

15 Inch nose

Section of 8 in nose and face plate

FIG. 11.—Bolt Layout for Three Sizes of Lathe Spindles

optional. For high speeds, Type A2 with 4 inches diameter is recommended. The sizes of noses for turret lathes are:

Up to $1\frac{3}{4}$ inches spindle bore	5-inch nose
Over $1\frac{3}{4}$ up to $2\frac{7}{16}$ inches spindle bore or up to $1\frac{3}{4}$ inches bar capacity	6-inch nose
Over $2\frac{7}{16}$ up to $3\frac{3}{8}$ inches spindle bore	8-inch nose
Over $3\frac{3}{8}$ up to $5\frac{3}{8}$ inches spindle bore	11-inch nose
Over $5\frac{3}{8}$ up to $8\frac{3}{8}$ inches spindle bore	15-inch nose
Over $8\frac{3}{8}$ up to 13 inches spindle bore	20-inch nose

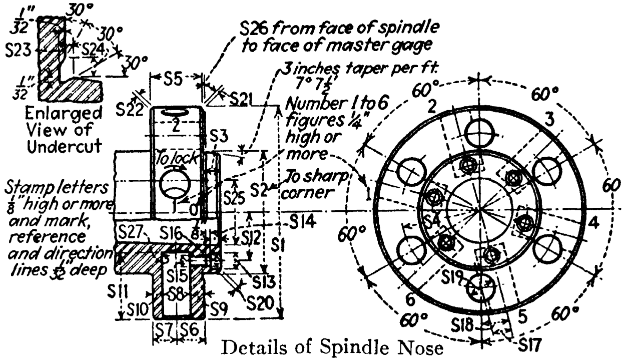
Type A1 nose is recommended for single-spindle automatics as follows:

Machines taking 6-inch chucks	5-inch nose
Machines taking 8-inch chucks	6-inch nose
Machines taking 10- and 12-inch chucks	8-inch nose
Machines taking 15- and 18-inch chucks	11-inch nose

For multiple-spindle automatics and engine lathes or for work spindles of grinding and hobbing machines, Type A1 or A2 of the following sizes is suggested. The type and size depend on the service.

Machines taking $4\frac{1}{2}$-inch chucks	4-inch nose
Machines taking 6-inch chucks	5-inch nose
Machines taking 8-inch chucks	6-inch nose
Machines taking 10- and 12-inch chucks	8-inch nose
Machines taking 15- and 18-inch chucks	11-inch nose

Dimensions of spindles are shown for 4, 11, and 15 inches. These show the spacing and arrangement for all sizes. The number of holes in each is given at the foot of Table 22. Details of the 6-hole spindle with cam lock are given in Table 21. The clamp-ring method and dimensions are seen in Table 23. Faceplate and chuck-body dimensions are shown in Table 24.



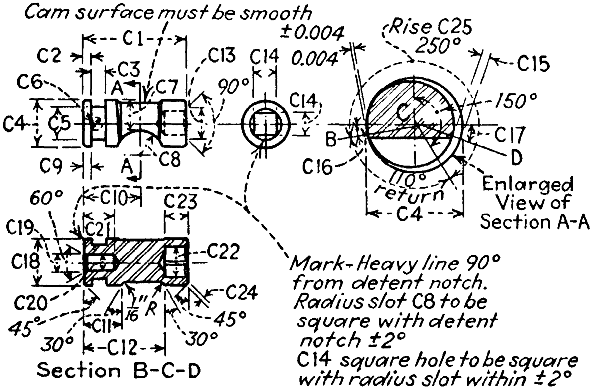
S26 from face of spindle to face of master gage

3 inches taper per ft. 7° 7½'

Number 1 to 6 figures ¼" high or more

Stamp letters ⅛" high or more and mark, reference and direction lines 1/32" deep

Details of Spindle Nose

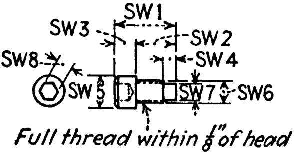


Cam surface must be smooth

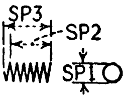
Mark-Heavy line 90° from detent notch. Radius slot C8 to be square with detent notch ±2°
C14 square hole to be square with radius slot within ±2°

Locking Cam

Cam Screw



Full thread within ⅛" of head



Cam Spring

Type *A1* is exactly as shown with tapped holes in both inner and outer bolt circles.

Type *A2* is same as shown, except omit holes in inner bolt circle.

Type *B1* is exactly as shown with clearance holes in outer bolt circle and tapped holes in inner bolt circle.

Type *B2* is same as shown, except omit tapped holes in inner bolt circle.

Type *C1* is exactly as shown with clamp-ring fit and tapped holes in both inner and outer bolt circles.

Type *C2* is same as shown, except omit tapped holes in inner bolt circle.

Type *C3* is same as shown, except omit tapped holes in both inner and outer bolt circles.

TABLE 21.—DIMENSIONS OF TYPE *D*1 SPINDLE NOSES
American Standard Lathe Spindle Noses for Turret Lathes and Automatic Lathes

Spindle Name	Symbol	Spindle Sizes in Inches						
		4-Inch Nose	5-Inch Nose	6-Inch Nose	8-Inch Nose	11-Inch Nose	15-Inch Nose	20-Inch Nose
Diameter of spindle	*S*1	$4\frac{5}{8}$	$5\frac{3}{4}$	$7\frac{1}{8}$	$8\frac{7}{8}$	$11\frac{3}{4}$	$15\frac{7}{8}$	$21\frac{1}{2}$
Pilot diameter	*S*2	2.5005+0.0005	3.2505+0.0005	4.1880+0 0005	5.50075+0.0005	7.75075+0.0005	11.251+0.001	16.251+0.001
Length of pilot	*S*3	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$
Radius of holes	*S*4	$1\frac{5}{8}$ ± 0.003	$2\frac{1}{16}$ ± 0.003	$2\frac{5}{8}$ ± 0.003	$3\frac{3}{8}$ ± 0.003	$4\frac{5}{8}$ ± 0.003	$6\frac{1}{2}$ ± 0.003	$9\frac{1}{8}$ ± 0.003
Minimum width of flange	*S*5	$1\frac{5}{16}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{3}{8}$	$2\frac{3}{4}$	$3\frac{1}{4}$
	*S*6	$\frac{11}{16}$	$\frac{13}{16}$	$\frac{15}{16}$	$1\frac{1}{16}$	$1\frac{1}{4}$	$1\frac{7}{16}$	$1\frac{11}{16}$
	*S*7	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{13}{16}$	$\frac{15}{16}$	$1\frac{1}{8}$	$1\frac{5}{16}$	$1\frac{9}{16}$
Diameter of hole for cam	*S*8	0.750+0.002	0.875+0.002	1.000+0 002	1.125+0.002	1.250+0.002	1.375+0.002	1.625+0.002
	*S*9	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$
	*S*10	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$
Depth of hole for cam	*S*11	$1\frac{39}{64}$+0 016	$1\frac{7}{8}$+0.016	$2\frac{1}{4}$+0.016	$2\frac{17}{32}$+0 016	$2\frac{15}{16}$+0.016	$3\frac{5}{16}$+0.016	$3\frac{11}{16}$+0.016
Radius of cam screw	*S*12	$\frac{15}{16}$ ± 0.004	$1\frac{1}{4}$ ± 0.004	$1\frac{5}{8}$ ± 0.004	$2\frac{1}{4}$ ± 0.004	$3\frac{3}{8}$ ± 0.004	$5\frac{1}{16}$ ± 0.004	$7\frac{1}{2}$ ± 0.004
Diameter of counterbore	*S*13	$\frac{25}{64}$	$\frac{29}{64}$	$\frac{37}{64}$	$\frac{37}{64}$	$\frac{37}{64}$	$\frac{37}{64}$	$\frac{37}{64}$
Depth of counterbore	*S*14	$\frac{9}{32}$	$\frac{11}{32}$	$\frac{13}{32}$	$\frac{13}{32}$	$\frac{13}{32}$	$\frac{13}{32}$	$\frac{13}{32}$
Thread	*S*15	$\frac{1}{4}$-20NC-3	$\frac{5}{16}$-18NC-3	$\frac{3}{8}$-16NC-3	$\frac{3}{8}$-16NC-3	$\frac{3}{8}$-16NC-3	$\frac{3}{8}$-16NC-3	$\frac{3}{8}$-16NC-3
Counterbore	*S*16	$\frac{17}{64}$	$\frac{21}{64}$	$\frac{25}{64}$	$\frac{25}{64}$	$\frac{25}{64}$	$\frac{25}{64}$	$\frac{25}{64}$
	*S*17	0.437 ± 0 004	0.531 ± 0 004	0.625 ± 0 004	0.719 ± 0 004	0.844 ± 0.004	0.969 ± 0.004	1.125 ± 0.004
Angle	*S*18	15°36′	14°35′	13°46′	12°18′	10°30′	8°35′	7°5′
Diameter of hole	*S*19	0.65625 ± 0.002	0.78125+0.002	0.90625+0.002	1.03125+0.002	1.21875+0.002	1.40625+0.002	1.65625+0.002
Chamfer	*S*20	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{8}$
Chamfer	*S*21	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{8}$
Chamfer	*S*22	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{8}$
Relief	*S*23	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{3}{32}$	$\frac{3}{32}$
Relief	*S*24	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{3}{16}$
Maximum hole	*S*25	$1\frac{1}{4}$	$1\frac{1}{4}$	$2\frac{1}{4}$	$3\frac{3}{8}$	$5\frac{3}{8}$	$8\frac{3}{8}$	13
Gage clearance	*S*26	0.002+0.002	0.002+0.002	0.002+0.002	0.003+0.002	0.003+0.002	0.004+0.004	0.004+0.004
Radius	*S*27	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$

TABLE 21 —*Continued*
Cams

Spindle Name	Symbol	Spindle Sizes in Inches						
		4-Inch Nose	5-Inch Nose	6-Inch Nose	8-Inch Nose	11-Inch Nose	15-Inch Nose	20-Inch Nose
Length of cam	*C*1	1.578−0.008	1.844−0.008	2.219−0.008	2.500−0.008	2.875−0.008	3.250−0.008	3.625−0.008
Width of flange	*C*2	0.125±0.004	0.125±0.004	0.156±0.004	0.1875±0.004	0.250±0.004	0.250±0.004	0.250±0.004
Width of groove	*C*3	0.187±0.004	0.243±0.004	0.296±0.004	0.296±0.004	0.296±0.004	0.296±0.004	0.296±0.004
Diameter of cam	*C*4	0.746−0.002	0.871−0.002	0.996−0.002	1.121−0.002	1.246−0.002	1.371−0.002	1.621−0.002
Diameter of bottom of groove	*C*5	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{11}{16}$	$\frac{13}{16}$	$\frac{15}{16}$	$1\frac{1}{16}$	$1\frac{5}{16}$
Diameter of cutter	*C*6	0.175±0.002	0.230±0.002	0.283±0.002	0.283±0.002	0.283±0.002	0.283±0.002	0.283±0.002
Location of slot	*C*7	$\frac{15}{32}-0.008$	$\frac{9}{16}-0.008$	$\frac{41}{64}-0.008$	$\frac{47}{64}-0.008$	$\frac{53}{64}-0.008$	$\frac{59}{64}-0.008$	$1\frac{5}{64}-0.008$
Radius of slot	*C*8	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{21}{32}$	$\frac{3}{4}$	$\frac{7}{8}$
To bottom detent notch	*C*9	0.094±0.004	0.094±0.004	0.125±0.004	0.156±0.004	0.219±0.004	0.219±0.004	0.219±0.004
Location of slot	*C*10	0.812±0.008	0.953±0.008	1.187±0.008	1.344±0.008	1.531±0.008	1.719±0.008	1.906±0.008
At Section *CD*	*C*11	$\frac{15}{32}$	$\frac{9}{16}$	$\frac{23}{32}$	$\frac{13}{16}$	$\frac{29}{32}$	1	$1\frac{1}{16}$
At Section *CD*	*C*12	$1\frac{3}{16}$	$1\frac{3}{8}$	$1\frac{11}{16}$	$1\frac{7}{8}$	$2\frac{5}{32}$	$2\frac{7}{16}$	$2\frac{3}{4}$
Diameter of center	*C*13	$\frac{1}{2}$	$\frac{19}{32}$	$\frac{11}{16}$	$\frac{25}{32}$	$\frac{7}{8}$	$\frac{31}{32}$	$1\frac{1}{8}$
Square hole	*C*14	0.379+0.012	0.441+0.012	0.504+0.012	0.566+0.012	0.629+0.012	0.691+0.012	0.816+0.012
At Section *CD*	*C*15	0.061+0.012	0.061+0.012	0.087+0.012	0.087+0.012	0.089+0.012	0.089+0.012	0.107+0.012
Angle	*C*16	10°	10°	10°	10°	15°	15°	15°
Angle	*C*17	15°	15°	20°	20°	20°	20°	20°
Chamfer	*C*18	$\frac{11}{16}$	$\frac{13}{16}$	$\frac{29}{32}$	$1\frac{1}{32}$	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{1}{2}$
Center	*C*19	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{7}{16}$	$\frac{7}{16}$	$\frac{7}{16}$	$\frac{7}{16}$
Diameter of hole	*C*20	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$
Depth of hole	*C*21	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$
Across corners	*C*22	0.530−0.016	0.615−0.016	0.700−0.016	0.785−0.016	0.875−0.016	0.960−0.016	1.135−0.016
Depth of hole	*C*23	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{13}{16}$
Chamfer	*C*24	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{3}{32}$	$\frac{3}{32}$	$\frac{3}{32}$
Rise in 250 degrees	*C*25	0.075	0.075	0.104	0.104	0.104	0.104	0.125

TABLE 21 —*Continued*

Cam Screw

Spindle Name	Symbol	Spindle Sizes in Inches						
		4-Inch Nose	5-Inch Nose	6-Inch Nose	8-Inch Nose	11-Inch Nose	15-Inch Nose	20-Inch Nose
Length of screw	*SW*1	$\frac{27}{32}$	$\frac{31}{32}$	$1\frac{3}{32}$	$1\frac{7}{32}$	$1\frac{13}{32}$	$1\frac{19}{32}$	$1\frac{25}{32}$
Under head	*SW*2	$\frac{19}{32}$	$\frac{21}{32}$	$\frac{23}{32}$	$\frac{27}{32}$	$1\frac{1}{32}$	$1\frac{7}{32}$	$1\frac{13}{32}$
Head	*SW*3	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$
Length of pilot	*SW*4	$\frac{3}{16}$	$\frac{7}{32}$	$\frac{7}{32}$	$\frac{7}{32}$	$\frac{7}{32}$	$\frac{7}{32}$	$\frac{7}{32}$
Diameter of head	*SW*5	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{9}{16}$
Thread	*SW*6	$\frac{1}{4}$-20NC-3	$\frac{5}{16}$-18NC-3	$\frac{3}{8}$-16NC-3	$\frac{3}{8}$-16NC-3	$\frac{3}{8}$-16NC-3	$\frac{3}{8}$-16NC-3	$\frac{3}{8}$-16NC-3
Diameter of pilot	*SW*7	0.175−0.002	0.230−0.002	0.283−0.002	0.283−0.002	0 283−0.002	0.283−0.002	0.283−0.002
Hex	*SW*8	$\frac{3}{16}$	$\frac{7}{32}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{5}{16}$

Cam Spring

Spindle Name	Symbol	4-Inch Nose	5-Inch Nose	6-Inch Nose	8-Inch Nose	11-Inch Nose	15-Inch Nose	20-Inch Nose
Diameter of spring	*SP*1	$\frac{7}{32}$	$\frac{9}{32}$	$\frac{11}{32}$	$\frac{11}{32}$	$\frac{11}{32}$	$\frac{11}{32}$	$\frac{11}{32}$
Working length	*SP*2	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$
Free length	*SP*3	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$
Load, in pounds	*SP*4	6 to 8	8 to 12	12 to 16	12 to 16	12 to 16	12 to 16	12 to 16

Tolerances of $\pm\frac{1}{64}$ are permissible unless otherwise specified when dimensions are expressed in common fractions.

TABLE 22.—DIMENSIONS OF TYPE *A*, TYPE *B*, AND TYPE *C* SPINDLE NOSES
American Standard Lathe-Spindle Noses for Turret Lathes and Automatic Lathes

Spindle Name	Symbol	Spindle Sizes in Inches						
		4-Inch Nose	5-Inch Nose	6-Inch Nose	8-Inch Nose	11-Inch Nose	15-Inch Nose	20-Inch Nose
Diameter of type *A* spindles	A_1	$4\frac{1}{4}$	$5\frac{1}{4}$	$6\frac{1}{2}$	$8\frac{1}{4}$	11	15	$20\frac{1}{2}$
Cam of type *B* spindles	A_2	$4\frac{1}{4}$	$5\frac{1}{4}$	$6\frac{1}{2}$	$8\frac{1}{4}$	11	15	$20\frac{1}{2}$
Diameter of type *C* spindles	A_3	$4\frac{7}{16}-0.002$	$5\frac{7}{16}-0.002$	$6\frac{3}{4}-0.002$	$8\frac{1}{2}-0.002$	$11\frac{1}{4}-0.004$	$15\frac{1}{4}-0.004$	$20\frac{3}{4}-0.004$
Pilot diameter	*B*	2.5005+0.0005	3.2505+0.0005	4.1880+0.0005	5.50075+0.0005	7.75075+0.0005	11.251+0.001	16.251+0.001
Maximum hole in type *A1* spindles	C_1		$1\frac{3}{4}$	$2\frac{7}{16}$	$3\frac{3}{8}$	$5\frac{3}{8}$	$8\frac{3}{8}$	13
Maximum hole in type *A2* spindles	C_2	2	$2\frac{5}{8}$	$3\frac{7}{16}$	$4\frac{5}{8}$	$6\frac{3}{4}$	$10\frac{1}{8}$	15
Length pilot*	*D*	0.500−0.002	0.5625−0.002	0.625−0.002	0.6875−0.002	0.750−0.002	0.9125−0.002	0.975−0.002
Location of driving button	*E*	$1\frac{5}{8}+0.003$	$2\frac{1}{16}\pm0.003$	$2\frac{5}{8}+0.003$	$3\frac{3}{8}\pm0.003$	$4\frac{5}{8}+0.006$	$6\frac{1}{2}+0.006$	$9\frac{1}{8}\pm0.006$
Radius of outer bolt circle	*F*	$1\frac{5}{8}\pm0.006$	$2\frac{1}{16}\pm0.006$	$2\frac{5}{8}\pm0.006$	$3\frac{3}{8}\pm0.006$	$4\frac{5}{8}\pm0.008$	$6\frac{1}{2}\pm0.008$	$9\frac{1}{8}\pm0.008$
Radius of inner bolt circle	*G*		$1\frac{7}{32}\pm0.006$	$1\frac{5}{8}\pm0.006$	$2\frac{3}{16}\pm0.006$	$3\frac{1}{4}\pm0.008$	$4\frac{7}{8}\pm0.008$	$7\frac{1}{4}\pm0.008$
Hole for driving button	*H*	0.5625+0.002	0.625+0.002	0.750+0.002	0.9375+0.002	1.125+0.002	1.375+0.002	1.625+0.002
Depth of counterbore	*I*	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{5}{8}$
Maximum radius	*J*	$\frac{1}{64}$	$\frac{1}{64}$	$\frac{1}{64}$	$\frac{1}{64}$	$\frac{1}{64}$	$\frac{1}{64}$	$\frac{1}{64}$
Counterbore	*K*	$\frac{25}{64}$	$\frac{21}{64}$	$\frac{21}{64}$	$\frac{25}{64}$	$\frac{25}{64}$	$\frac{33}{64}$	$\frac{33}{64}$
Depth of counterbore	*L*	$\frac{3}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$
Thread	*M*	$\frac{3}{8}$-16NC-3	$\frac{5}{16}$-18NC-3	$\frac{5}{16}$-18NC-3	$\frac{3}{8}$-16NC-3	$\frac{3}{8}$-16NC-3	$\frac{1}{2}$-13NC-3	$\frac{1}{2}$-13NC-3
Tap drill	*N*	$\frac{5}{16}$	$\frac{17}{64}$	$\frac{17}{64}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{27}{64}$	$\frac{27}{64}$
Full-depth thread	*O*	$\frac{9}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{7}{8}$	$\frac{7}{8}$
Thread	*P*	$\frac{7}{16}$-14NC-3	$\frac{7}{16}$-14NC-3	$\frac{1}{2}$-13NC-3	$\frac{5}{8}$-11NC-3	$\frac{3}{4}$-10NC-3	$\frac{7}{8}$-9NC-3	1-8NC-3
Tap drill	*R*	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{27}{64}$	$\frac{17}{32}$	$\frac{21}{32}$	[illegible]	$\frac{7}{8}$
Full-depth thread	*S*	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{7}{8}$	$1\frac{1}{16}$	$1\frac{1}{4}$	$1\frac{7}{16}$	$1\frac{5}{8}$
Counterbore	*T*	$\frac{29}{64}$	$\frac{29}{64}$	$\frac{33}{64}$	$\frac{41}{64}$	$\frac{49}{64}$	$\frac{57}{64}$	$1\frac{1}{64}$

Depth of counterbore	*U*	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$
Minimum width of flange	*V*	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{3}{8}$	$1\frac{5}{8}$	$1\frac{7}{8}$
Clearance hole in type *B* spindle	*W*	$\frac{15}{32}$	$\frac{15}{32}$	$\frac{17}{32}$	$\frac{21}{32}$	$\frac{51}{64}$	$\frac{59}{64}$	$1\frac{3}{64}$
Chamfer	*X*	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$
Gage clearance	*Y*	0.002+0 002	0.002+0.002	0.002+0.002	0.003+0 002	0.003+0 002	0 004+0.004	0.004+0.004
Clamp-ring fit—to sharp corner	Z_1	0.3125−0.002	0.375−0.002	0.4375−0 004	0 500−0 006	0.625−0 008	0 750−0.008	0.875−0.008
Root diameter for clamp-ring fit	Z_2	3.875−0 016	4.750−0 016	5.9375−0 016	7 5625−0 016	10.1875−0 016	14 0625−0.016	19.3125−0.016
Maximum radius	Z_3	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$
Chamfer	*AA*	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{8}$
Chamfer	*BB*	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{8}$
Chamfer	*CC*	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{8}$
Chamfer	*DD*	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{8}$
Chamfer	*EE*	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$
Diameter driving button	*FF*	0.5625−0.001	0.625−0.001	0.750−0 001	0 9375−0 001	1.125−0 001	1 375−0.001	1.625−0.001
Length driving button	*GG*	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{15}{16}$
Counterbore	*HH*		$\frac{29}{64}$	$\frac{29}{64}$	$\frac{37}{64}$	$\frac{37}{64}$	$\frac{49}{64}$	$\frac{49}{64}$
Depth counterbore	*II*		$\frac{13}{64}$	$\frac{13}{64}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{21}{64}$	$\frac{21}{64}$
Diameter of hole	*JJ*		$\frac{21}{64}$	$\frac{21}{64}$	$\frac{25}{64}$	$\frac{25}{64}$	$\frac{33}{64}$	$\frac{33}{64}$
Chamfer	*KK*		$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$
Thread	*LL*	$\frac{3}{8}$-16NC-3	$\frac{5}{16}$-18NC-3	$\frac{5}{16}$-18NC-3	$\frac{3}{8}$-16NC-3	$\frac{3}{8}$-16NC-3	$\frac{1}{2}$-13NC-3	$\frac{1}{2}$-13NC-3
Length under head	*MM*	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{4}$	$1\frac{3}{8}$
	NN		$\frac{13}{64}$	$\frac{13}{64}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{21}{64}$	$\frac{21}{64}$
Full-length thread	*OO*	$\frac{5}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	1	$1\frac{1}{8}$
Diameter of head	*PP*		$\frac{7}{16}$	$\frac{7}{16}$	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{3}{4}$	$\frac{3}{4}$
	RR		$\frac{3}{64}$	$\frac{3}{64}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{5}{64}$	$\frac{5}{64}$
Slot	*SS*		0.065 to 0 079	0 065 to 0 079	0 074 to 0.088	0 074 to 0 088	0.094 to 0.110	0.094 to 0.110
	TT		$\frac{3}{32}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{5}{32}$
	UU	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{3}{32}$	$\frac{3}{32}$
	VV	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{3}{16}$
	WW	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{5}{16}$
	XX	$\frac{5}{16}$ HEX						
Number of holes		11	19	19	19	19	23	23

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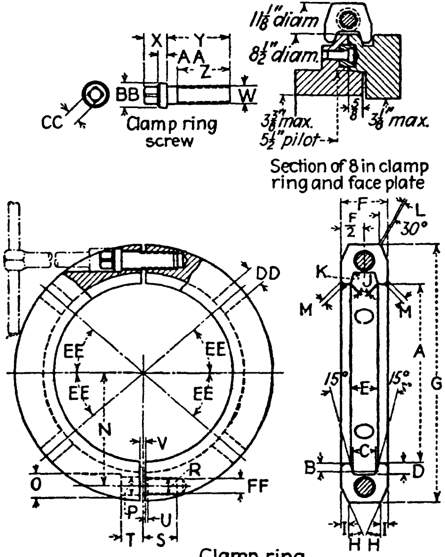
* Use length of pilot S3, Table II, in place of length of pilot D, Table 3, on spindles A2, C2, and C3.

TABLE 23.—DIMENSIONS OF CLAMP RINGS FOR TYPE *C* SPINDLE NOSES
American Standard Lathe Spindle Noses for Turret Lathes and Automatic Lathes



Clamp ring screw

Section of 8 in clamp ring and face plate

Clamp ring

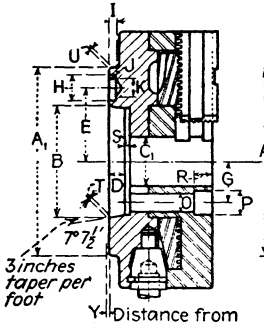
Dimension of Clamp Rings for Type C Spindle

Spindle Name	Symbol	Spindle Sizes in Inches						
		4-Inch Nose	5-Inch Nose	6-Inch Nose	8-Inch Nose	11-Inch Nose	15-Inch Nose	20-Inch Nose
Clamp-ring bore	*A*	4+0.002	4 15/16+0.002	6 3/16+0.002	7 13/16+0.002	10 7/16+0.004	14 5/16+0.004	19 9/16+0.004
	B	0.21875	0.2500	0.28125	0.34375	0.40625	0.46875	0.59375
Width at depth *B*	*C*	0.626+0.002	0.751+0.002	0.877+0.002	1.002+0.002	1.252+0.004	1.504+0.004	1.754+0.004
Depth	*D*	9/32+0.008	11/32+0.008	13/32+0.008	15/32+0.008	17/32+0.008	19/32+0.008	25/32+0.008
To sharp corners	*E*	0.743+0.002	0.885+0.002	1.028+0.002	1.186+0.002	1.470+0.004	1.755+0.004	2.072+0.004
Width	*F*	1 1/4	1 1/2	1 3/4	2	2 1/2	3	3 1/2
Outside diameter	*G*	6 1/16	7 3/8	9 1/16	11 1/8	14 1/4	18 1/2	24 1/8
Angle	*H*	15°	20°	20°	20°	25°	30°	30°
Chamfer	*I*	3/16	1/4	9/32	5/16	7/16	1/2	9/16
Chamfer	*J*	1/32	1/32	1/32	1/32	1/32	1/32	1/32
Radius	*K*	1/32	1/32	1/16	1/16	1/16	1/16	1/16
Chamfer	*L*	1/16	1/16	1/16	1/16	1/8	1/8	1/8
Chamfer	*M*	1/16	1/16	1/8	3/16	3/16	1/4	1/4
Location of screw	*N*	2 19/32	3 3/16	3 15/16	4 7/8	6 5/16	8 3/8	11 3/16
Diameter of counterbore	*O*	21/32	25/32	29/32	1 1/32	1 3/16	1 3/8	1 1/2
Drill	*P*	15/32	17/32	21/32	25/32	59/64	1 3/64	1 11/64
Thread	*R*	7/16-14NC-3	1/2-13NC-3	5/8-11NC-3	3/4-10NC-3	7/8-9NC-3	1-8NC-3	1 1/8-7NC-3
Full-depth thread	*S*	1	1 1/8	1 1/4	1 1/2	1 3/4	2	2 1/4
	T	9/16	11/16	13/16	15/16	1 3/8	1 9/16	1 13/16
Depth of counterbore	*U*	1/16	1/16	1/16	1/16	1/16	1/16	1/16
Width saw cut	*V*	1/8	1/8	1/8	1/8	1/8	3/16	3/16
Thread	*W*	7/16-14NC-3	1/2-13NC-3	5/8-11NC-3	3/4-10NC-3	7/8-9NC-3	1-8NC-3	1 1/8-7NC-3
	X	7/16	11/16	13/16	15/16	1 1/8	1 5/16	1 7/16
	Y	1 3/8	1 5/8	1 7/8	2 1/4	2 7/8	3 1/4	3 3/4
Full-length thread	*Z*	1	1 1/4	1 1/2	1 3/4	2	2 1/4	2 1/2
	AA	7/32	9/32	11/32	13/32	15/32	17/32	19/32
Diameter of head	*BB*	5/8	3/4	7/8	1	1 1/8	1 5/16	1 7/16
Square head	*CC*	5/16	3/8	7/16	1/2	9/16	5/8	11/16
Inspection holes	*DD*	15/32	17/32	21/32	25/32	59/64	1 3/64	1 11/64
Angle	*EE*	40°	40°	40°	40°	45°	45°	45°
Tap drill	*FF*	3/8	27/64	17/32	21/32	49/64	7/8	63/64

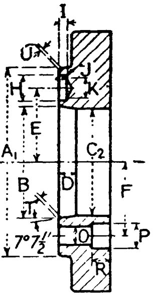
Tolerances of ±1/64 are permissible unless otherwise specified when dimensions are expressed in common fractions.

TABLE 24.—DIMENSIONS OF CHUCKS AND FACEPLATES FOR TYPE *A*, TYPE *B*, AND TYPE *C* SPINDLE NOSES

American Standard Lathe Spindle Noses for Turret Lathes and Automatic Lathes

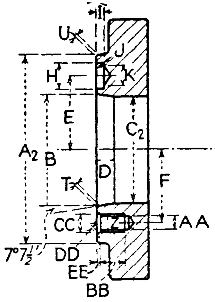


Y—Distance from face of chuck to face of master gage Table 24

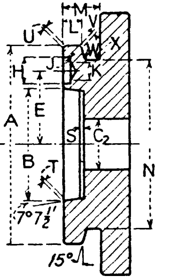


Chucks or face plates held by socket head cap screws on outer bolt circle

Scroll chucks held by socket head cap screws on inner bolt circle



Chucks or face plates to be D by type B studs to type B spindles



Chucks or face plates held by clamp rings to type C spindles

Spindle Name		4-Inch Nose	5-Inch Nose	6-Inch Nose	8-Inch Nose	11-Inch Nose	15-Inch Nose	20-Inch Nose
Diam. of flange	A_1	$4\frac{1}{4}$	$5\frac{1}{4}$	$6\frac{1}{2}$	$8\frac{1}{4}$	11	15	$20\frac{1}{2}$
Diam. of flange	A_2	$4\frac{1}{4}$	$5\frac{1}{4}$	$6\frac{1}{2}$	$8\frac{1}{4}$	11	15	$20\frac{1}{2}$
Diam. of flange	A_3	$4\frac{7}{16}-0.002$	$5\frac{7}{16}-0.002$	$6\frac{3}{4}-0.002$	$8\frac{1}{2}-0.002$	$11\frac{1}{4}-0.004$	$15\frac{1}{4}-0.004$	$20\frac{3}{4}-0.004$
Pilot diam.	B	2.500−0.0005	3.250−0.0005	4.1875−0.0005	5.500−0.0005	7.750−0.0005	11.250−0.001	16.250−0.001
Maximum hole	C_1		$1\frac{1}{2}$	$2\frac{1}{8}$	$3\frac{1}{8}$	$5\frac{1}{8}$	$8\frac{1}{4}$	$12\frac{3}{4}$
Maximum hole	C_2	$2\frac{25}{64}$	$3\frac{1}{8}$	$4\frac{3}{64}$	$5\frac{11}{32}$	$7\frac{37}{64}$	$11\frac{1}{16}$	$16\frac{3}{64}$
Depth of pilot hole	D	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$
Location of driving button	E	$1\frac{5}{8}\pm0.003$	$2\frac{1}{16}\pm0.003$	$2\frac{5}{8}\pm0.003$	$3\frac{3}{8}\pm0.003$	$4\frac{5}{8}\pm0.006$	$6\frac{1}{2}\pm0.006$	$9\frac{1}{8}\pm0.006$

Radius of outer bolt circle	*F*	$1\frac{5}{8} \pm 0.006$	$2\frac{1}{16} \pm 0.006$	$2\frac{5}{8} \pm 0.006$	$3\frac{3}{8} \pm 0.006$	$4\frac{5}{8} \pm 0.008$	$6\frac{1}{2} \pm 0.008$	$9\frac{1}{8} \pm 0.008$
Radius of inner bolt circle	*G*		$1\frac{7}{32} \pm 0.006$	$1\frac{5}{8} \pm 0.006$	$2\frac{3}{16} \pm 0.006$	$3\frac{1}{4} \pm 0.008$	$4\frac{7}{8} \pm 0.008$	$7\frac{1}{4} \pm 0.008$
Hole for driving button	*H*	$\frac{37}{64} + 0.004$	$\frac{41}{64} + 0.004$	$\frac{49}{64} + 0.004$	$\frac{61}{64} + 0.004$	$1\frac{5}{32} + 0.004$	$1\frac{13}{32} + 0.004$	$1\frac{21}{32} + 0.004$
Depth of driving button hole	*I*	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$
Radius	*J*	$\frac{1}{64}$	$\frac{1}{64}$	$\frac{1}{64}$	$\frac{1}{64}$	$\frac{1}{64}$	$\frac{1}{64}$	$\frac{1}{64}$
Minimum	*K*		$\frac{7}{16}$	$\frac{7}{16}$	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{3}{4}$	$\frac{3}{4}$
To sharp corner	*L*	$0.3125 - 0.002$	$0.375 - 0.002$	$0.4375 - 0.002$	$0.500 - 0.004$	$0.625 - 0.004$	$0.750 - 0.008$	$0.875 - 0.008$
Minimum for clamp ring	*M*	$\frac{11}{16}$	$\frac{13}{16}$	$\frac{15}{16}$	$1\frac{1}{16}$	$1\frac{5}{16}$	$1\frac{5}{8}$	$1\frac{7}{8}$
Root diam. for clamp-ring fit	*N*	$3.875 - 0.016$	$4.750 - 0.016$	$5.9375 - 0.016$	$7.5625 - 0.016$	$10.187 - 0.016$	$14.0625 - 0.016$	$19.3125 - 0.016$
Clearance holes for bolts	*O*	$\frac{15}{32}$	$\frac{15}{32}$	$\frac{17}{32}$	$\frac{21}{32}$	$\frac{51}{64}$	$\frac{59}{64}$	$1\frac{3}{64}$
Counterbore for bolt head	*P*	$\frac{21}{32}$	$\frac{21}{32}$	$\frac{25}{32}$	$\frac{29}{32}$	$1\frac{3}{64}$	$1\frac{11}{64}$	$1\frac{23}{64}$
Depth of counterbore for bolt head	*R*	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{11}{16}$	$\frac{13}{16}$	$\frac{15}{16}$	$1\frac{1}{16}$
Minimum depth of counterbore	*S*	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$
Chamfer	*T*	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{8}$
Chamfer	*U*	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{8}$
Chamfer	*V*	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{8}$
Radius	*W*	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$
Radius	*X*	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$
Gage clearance	*Y*	$0.002 - 0.002$	$0.002 - 0.002$	$0.002 - 0.002$	$0.002 - 0.002$	$0.002 - 0.002$	$0.004 - 0.004$	$0.004 - 0.004$
Thread	*Z*	$\frac{7}{16}$-14NC-3	$\frac{7}{16}$-14NC-3	$\frac{1}{2}$-13NC-3	$\frac{5}{8}$-11NC-3	$\frac{3}{4}$-10NC-3	$\frac{7}{8}$-9NC-3	1-8NC-3
Tap drill	*AA*	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{27}{64}$	$\frac{17}{32}$	$\frac{21}{32}$	$\frac{49}{64}$	$\frac{7}{8}$
Full-depth thread	*BB*	$\frac{11}{16}$	$\frac{11}{16}$	$\frac{13}{16}$	1	$1\frac{3}{16}$	$1\frac{3}{8}$	$1\frac{9}{16}$
Counterbore	*CC*	$\frac{29}{64}$	$\frac{29}{64}$	$\frac{33}{64}$	$\frac{41}{64}$	$\frac{49}{64}$	$\frac{57}{64}$	$1\frac{1}{64}$
Chamfer	*DD*	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$
Depth of counterbore	*EE*	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$
Total depth, counterbore*	*FF*	$0.500 + 0.002$	$0.5625 + 0.002$	$0.625 + 0.002$	$0.6875 + 0.002$	$0.750 + 0.002$	$0.8125 + 0.002$	$0.875 + 0.002$

Tolerances of $\pm \frac{1}{64}$ are permissible unless otherwise specified when dimensions are expressed in common fractions.

* Use dimension *FF* in place of $D + S$ for total depth of counterbore, to give contact between end of pilot on spindle and bottom of counterbore in chuck when necessary to limit the dishing of chucks held by screws in inner bolt circle of spindles Type *A*1, *B*1, or *C*1.

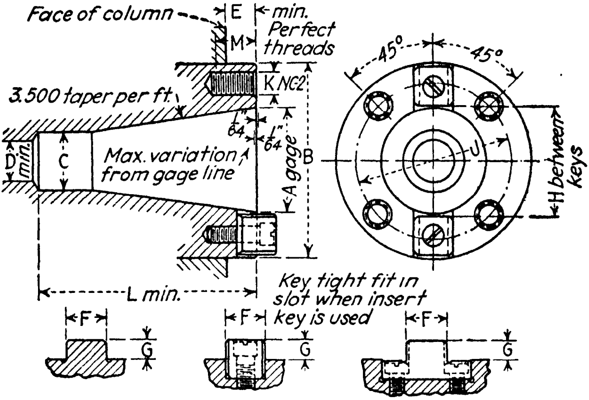


FIG. 12.—Standard Milling-Machine Nose

ESSENTIAL SPINDLE-NOSE DIMENSIONS

	No. 10 ($\frac{5}{8}$ Inch)	No. 20 ($\frac{7}{8}$ Inch)	No. 30 ($1\frac{1}{4}$ Inches)	No. 40 ($1\frac{3}{4}$ Inches)	No. 50 ($2\frac{3}{4}$ Inches)	No. 60 ($4\frac{1}{4}$ Inches)
A	$\frac{5}{8}$	$\frac{7}{8}$	$1\frac{1}{4}$	$1\frac{3}{4}$	$2\frac{3}{4}$	$4\frac{1}{4}$
B			2.7493 2.7488	3.4993 3.4988	5.0618 5.0613	8.7180 8.7175
C			0.692 0.685	1.005 0.997	1.568 1.559	2.381 2.371
D			$\frac{21}{32}$	$\frac{21}{32}$	$1\frac{1}{16}$	$1\frac{3}{8}$
E			$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$1\frac{1}{2}$
F			0.6255 0.6252	0.6255 0.6252	1.0006 1.0002	1.000 0.999
G			$\frac{5}{16}$	$\frac{5}{16}$	$\frac{1}{2}$	$\frac{1}{2}$
H			1.315 1.285	1.819 1.807	2.819 2.807	4.819 4.807
J			2.130 2.120	2.630 2.620	4.005 3.955	7.005 6.995
K			$\frac{3}{8}$-16	$\frac{1}{2}$-13	$\frac{5}{8}$-11	$\frac{3}{4}$-10
L	$\frac{15}{16}$	$1\frac{5}{16}$	$2\frac{7}{8}$	$3\frac{7}{8}$	$5\frac{1}{2}$	$8\frac{5}{8}$
M			$\frac{5}{8}$	$\frac{13}{16}$	1	$1\frac{1}{4}$

Above dimensions approved as N.M.T.B.A. standard by the Committee on Milling Machine Spindle Nose Standardization of National Machine Tool Builders Association, July 11, 1938.

Above construction covered by U. S. Patent 1794361. For license to use any part of this construction apply to F. A. Parsons, patent attorney, Mariner Tower, Milwaukee, Wis.

The patents on these designs have now been dedicated to the public and were adopted as an American standard in 1943.

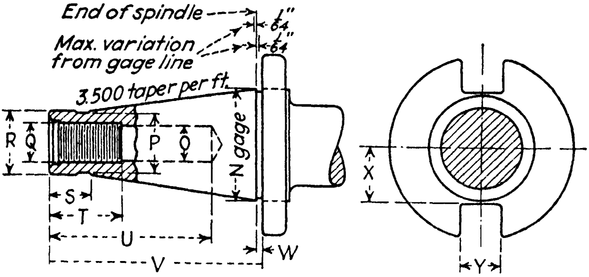


FIG. 13*a*.—Standard Arbor for Milling Machines

ESSENTIAL ARBOR DIMENSIONS

	No. 10 (⅝ Inch)	No. 20 (⅞ Inch)	No. 30 (1¼ Inches)	No. 40 (1¾ Inches)	No. 50 (2¾ Inches)	No. 60 (4¼ Inches)
N	⅝	⅞	1¼	1¾	2¾	4¼
O			27/64	17/32	⅞	1 7/64
P			41/64	15/16	1½	2 9/32
Q			½-13	⅝-11	1-8	1¼-7
R			0.675 0.673	0.987 0.985	1.549 1.547	2.361 2.359
S			11/16	1	1	1¾
T			1	1⅛	1¾	2¼
U			2	2 15/16	3½	4¼
V			2¾	3¾	5⅛	8 5/16
W			1/16	1/16	⅛	⅛
X			0.640 0.625	0 890 0.875	1.390 1.375	2 400 2.390
Y			0 630 0.640	0.630 0.640	1.008 1.018	1.008 1.018

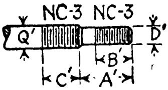


FIG. 13*b*.—Draw-In Bolt

A'			1 1/16	11/16	1¼	1¾
B'			⅞	15/16	1¼	1⅜
C'			¾	1⅛	1⅜	2
Q'			½-13	⅝-11	1-8	1¼-7
D'			⅜-16	½-13	⅝-11	1-8

Above dimensions approved as N.M.T.B.A. standard by the Committee on Milling Machine Spindle Nose Standardization of National Machine Tool Builders Association, July 11, 1938.

Above construction covered by U. S. Patent 1794361. For license to use any part of this construction, apply to F. A. Parsons, patent attorney, Mariner Tower, Milwaukee, Wis.

STANDARD MILLING-MACHINE SPINDLES AND ARBORS

Miling-machine spindles and arbors were standardized by the leading builders of milling machines in 1927. These now comprise four sizes as shown in Figs. 12 and 13. These sizes were adopted July 11, 1938. The two smaller sizes have not yet been standardized.

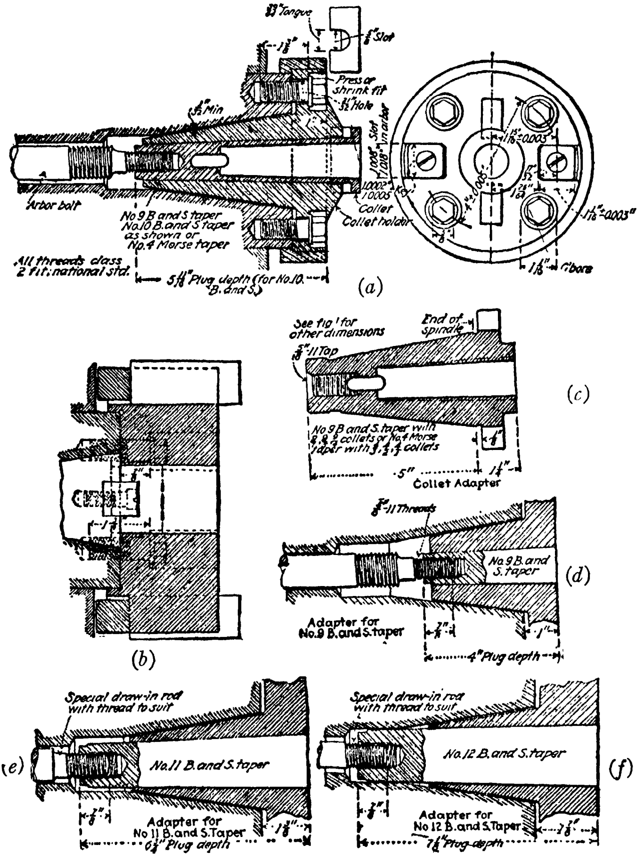
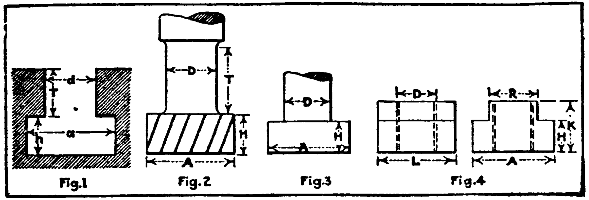


FIG. 14.—Adapter for Milling-Machine Spindles

Five adapters for use with the standard spindle ends are shown in Fig. 14, where *a* registers over outside of spindle end is bolted to its face. It is used for arbors and tools having a threaded end for draw-in bolt. At *b* is a face mill held by four screws and

STANDARD T-SLOTS FOR MACHINE TOOLS



All dimensions in inches. A tolerance of *plus* 0.001 inch is allowed for width of throat when tongues must fit. There is a secondary standard with the width of throat the same as the nominal diameter of T bolt. Width of tongue used with these slots is given in Table 29.

TABLE 25.—DIMENSIONS AND TOLERANCES FOR STANDARD T SLOTS—FIG. 1

Diameter of T-bolt	Width of Throat d	Depth of Throat T		Head Space Dimensions and Tolerances					
				Width			Depth		
		Maximum	Minimum	Maximum (Basic)	Tolerance (Minus)	Minimum	Maximum (Basic)	Tolerance (Minus)	Minimum
$\frac{1}{4}$	$\frac{9}{32}$	$\frac{3}{8}$	$\frac{1}{8}$	$\frac{9}{16}$	0.063	$\frac{1}{2}$	$\frac{15}{64}$	0.031	$\frac{13}{64}$
$\frac{5}{16}$	$\frac{11}{32}$	$\frac{7}{16}$	$\frac{5}{32}$	$\frac{21}{32}$	0.063	$\frac{19}{32}$	$\frac{17}{64}$	0.031	$\frac{15}{64}$
$\frac{3}{8}$	$\frac{7}{16}$	$\frac{9}{16}$	$\frac{7}{32}$	$\frac{25}{32}$	0.063	$\frac{23}{32}$	$\frac{21}{64}$	0.031	$\frac{19}{64}$
$\frac{1}{2}$	$\frac{9}{16}$	$\frac{11}{16}$	$\frac{5}{16}$	$\frac{31}{32}$	0.063	$\frac{29}{32}$	$\frac{25}{64}$	0.031	$\frac{23}{64}$
$\frac{5}{8}$	$\frac{11}{16}$	$\frac{7}{8}$	$\frac{7}{16}$	$1\frac{1}{4}$	0.063	$1\frac{3}{16}$	$\frac{31}{64}$	0.031	$\frac{29}{64}$
$\frac{3}{4}$	$\frac{13}{16}$	$1\frac{1}{16}$	$\frac{9}{16}$	$1\frac{15}{32}$	0.094	$1\frac{3}{8}$	$\frac{5}{8}$	0.031	$\frac{19}{32}$
1	$1\frac{1}{16}$	$1\frac{1}{4}$	$\frac{3}{4}$	$1\frac{27}{32}$	0.094	$1\frac{3}{4}$	$\frac{53}{64}$	0.047	$\frac{25}{32}$
$1\frac{1}{4}$	$1\frac{5}{16}$	$1\frac{9}{16}$	1	$2\frac{7}{32}$	0.094	$2\frac{1}{8}$	$1\frac{3}{32}$	0.063	$1\frac{1}{32}$
$1\frac{1}{2}$	$1\frac{9}{16}$	$1\frac{15}{16}$	$1\frac{1}{4}$	$2\frac{21}{32}$	0.094	$2\frac{9}{16}$	$1\frac{11}{32}$	0.063	$1\frac{9}{32}$

TABLE 26.—DIMENSIONS FOR T-SLOT CUTTERS—FIG. 2

Width of Throat		Thickness of Cutter H		Diameter of Cutters A		Diameter of Neck D	Length of Neck T
Standard	Nominal Bolt Size	Maximum	Minimum (Worn)	Maximum	Minimum (Worn)		
$\frac{9}{32}$	$\frac{1}{4}$	$\frac{15}{64}$	$\frac{13}{64}$	$\frac{9}{16}$	$\frac{1}{2}$	$\frac{17}{64}$	$\frac{3}{8}$
$\frac{11}{32}$	$\frac{5}{16}$	$\frac{17}{64}$	$\frac{15}{64}$	$\frac{21}{32}$	$\frac{19}{32}$	$\frac{21}{64}$	$\frac{7}{16}$
$\frac{7}{16}$	$\frac{3}{8}$	$\frac{21}{64}$	$\frac{19}{64}$	$\frac{25}{32}$	$\frac{23}{32}$	$\frac{13}{32}$	$\frac{9}{16}$
$\frac{9}{16}$	$\frac{1}{2}$	$\frac{25}{64}$	$\frac{23}{64}$	$\frac{31}{32}$	$\frac{29}{32}$	$\frac{17}{32}$	$\frac{11}{16}$
$\frac{11}{16}$	$\frac{5}{8}$	$\frac{31}{64}$	$\frac{29}{64}$	$1\frac{1}{4}$	$1\frac{3}{16}$	$\frac{21}{32}$	$\frac{7}{8}$
$\frac{13}{16}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{19}{32}$	$1\frac{15}{32}$	$1\frac{3}{8}$	$\frac{25}{32}$	$1\frac{1}{16}$
$1\frac{1}{16}$	1	$\frac{53}{64}$	$\frac{25}{32}$	$1\frac{27}{32}$	$1\frac{3}{4}$	$1\frac{1}{32}$	$1\frac{1}{4}$
$1\frac{5}{16}$	$1\frac{1}{4}$	$1\frac{3}{32}$	$1\frac{1}{32}$	$2\frac{7}{32}$	$2\frac{1}{8}$	$1\frac{9}{32}$	$1\frac{9}{16}$
$1\frac{9}{16}$	$1\frac{1}{2}$	$1\frac{11}{32}$	$1\frac{9}{32}$	$2\frac{21}{32}$	$2\frac{9}{16}$	$1\frac{17}{32}$	$1\frac{15}{16}$

TABLE 27.—DIMENSIONS FOR STANDARD T BOLTS—FIG. 3

Diameter of T-bolt	Threads per Inch	Bolt Heads Dimensions and Tolerances						
		Width across Flats, A			Height, H			
		Maximum (Basic)	Tolerance (Minus)	Minimum	Width across Corners	Maximum (Basic)	Tolerance (Minus)	Minimum
$\frac{1}{4}$	20	$\frac{15}{32}$	0.031	$\frac{7}{16}$	0.663	$\frac{5}{32}$	0.016	$\frac{9}{64}$
$\frac{5}{16}$	18	$\frac{9}{16}$	0.031	$\frac{17}{32}$	0.796	$\frac{3}{16}$	0.016	$\frac{11}{64}$
$\frac{3}{8}$	16	$\frac{11}{16}$	0.031	$\frac{21}{32}$	0.972	$\frac{1}{4}$	0.016	$\frac{15}{64}$
$\frac{1}{2}$	13	$\frac{7}{8}$	0.031	$\frac{27}{32}$	1.238	$\frac{5}{16}$	0.016	$\frac{19}{64}$
$\frac{5}{8}$	11	$1\frac{1}{8}$	0.031	$1\frac{3}{32}$	1.591	$\frac{13}{32}$	0.016	$\frac{25}{64}$
$\frac{3}{4}$	10	$1\frac{5}{16}$	0.031	$1\frac{9}{32}$	1.856	$\frac{17}{32}$	0.031	$\frac{1}{2}$
1	8	$1\frac{11}{16}$	0.031	$1\frac{21}{32}$	2.387	$\frac{11}{16}$	0.031	$\frac{21}{32}$
$1\frac{1}{4}$	7	$2\frac{1}{16}$	0.031	$2\frac{1}{32}$	2.917	$\frac{15}{16}$	0.031	$\frac{29}{32}$
$1\frac{1}{2}$	6	$2\frac{1}{2}$	0.031	$2\frac{15}{32}$	3.536	$1\frac{3}{16}$	0.031	$1\frac{5}{32}$

TABLE 28.—DIMENSIONS AND TOLERANCES FOR STANDARD T NUTS—FIG. 4

Tap for Stud D		Width of Throat T-slot	Width of Tongue R			Width of Nut A			Height of Nut H			Total Thickness Including Tongue K	Length of Nut L
Diameter	Threads per Inch		Maximum Basic	Tolerance, Minus	Minimum	Maximum, Basic	Tolerance, Minus	Minimum	Maximum, Basic	Tolerance, Minus	Minimum		
$\frac{1}{4}$	20	$\frac{11}{32}$	0.330	0.010	0.320	$\frac{9}{16}$	0.031	$\frac{17}{32}$	$\frac{3}{16}$	0.016	$\frac{11}{64}$	$\frac{9}{32}$	$\frac{9}{16}$
$\frac{5}{16}$	18	$\frac{7}{16}$	0.418	0.010	0.408	$\frac{11}{16}$	0.031	$\frac{21}{32}$	$\frac{1}{4}$	0.016	$\frac{15}{64}$	$\frac{3}{8}$	$\frac{9}{16}$
$\frac{3}{8}$	16	$\frac{9}{16}$	0.543	0.010	0.533	$\frac{7}{8}$	0.031	$\frac{27}{32}$	$\frac{5}{16}$	0.016	$\frac{19}{64}$	$\frac{17}{32}$	$\frac{7}{8}$
$\frac{1}{2}$	13	$\frac{11}{16}$	0.668	0.010	0.658	$1\frac{1}{8}$	0.031	$1\frac{3}{32}$	$\frac{13}{32}$	0.016	$\frac{25}{64}$	$\frac{5}{8}$	$1\frac{1}{8}$
$\frac{5}{8}$	11	$\frac{13}{16}$	0.783	0.010	0.773	$1\frac{5}{16}$	0.031	$1\frac{9}{32}$	$\frac{17}{32}$	0.031	$\frac{1}{2}$	$\frac{25}{32}$	$1\frac{5}{16}$
$\frac{3}{4}$	10	$1\frac{1}{16}$	1.033	0.015	1.018	$1\frac{11}{16}$	0.031	$1\frac{21}{32}$	$\frac{11}{16}$	0.031	$\frac{21}{32}$	1	$1\frac{11}{16}$
1	8	$1\frac{5}{16}$	1.273	0.015	1.258	$2\frac{1}{16}$	0.031	$2\frac{1}{32}$	$\frac{15}{16}$	0.031	$\frac{29}{32}$	$1\frac{5}{16}$	$2\frac{1}{16}$
$1\frac{1}{4}$	7	$1\frac{9}{16}$	1.523	0.015	1.508	$2\frac{1}{2}$	0.031	$2\frac{15}{32}$	$1\frac{3}{16}$	0.031	$1\frac{5}{32}$	$1\frac{5}{8}$	$2\frac{1}{2}$

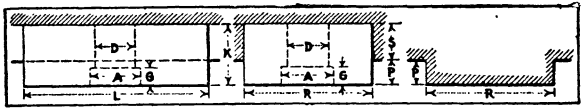


FIG. 5.—Standard Inserted and Solid Tongues

TABLE 29.—INSERTED AND SOLID TONGUES AND SEATS FOR SINGLE-WIDTH T SLOTS

Diameter of T-bolt	Tongue Dimensions			Depth of Seat S	Total Thickness K	Diameter of Screw D	Screw Dimensions			Thickness of Head G
	Width R	Length L	Projection P				Number of Screw	Threads per Inch	Diameter of Head A	
$\frac{1}{4}$	$\frac{9}{32}$	$\frac{3}{8}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{7}{32}$	0.125	5	40	0.196	0.081
$\frac{5}{16}$	$\frac{11}{32}$	$\frac{15}{32}$	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{9}{32}$	0.164	8	32	0.260	0.107
$\frac{3}{8}$	$\frac{7}{16}$	$\frac{9}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{5}{16}$	0.190	10	24	0.303	0.124
$\frac{1}{2}$	$\frac{9}{16}$	$\frac{3}{4}$	$\frac{1}{8}$	$\frac{7}{32}$	$\frac{11}{32}$	$\frac{1}{4}$	..	20	0.375	0.130
$\frac{5}{8}$	$\frac{11}{16}$	$\frac{15}{16}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{4}$	..	20	0.375	0.130
$\frac{3}{4}$	$\frac{13}{16}$	1$\frac{1}{8}$	$\frac{5}{32}$	$\frac{9}{32}$	$\frac{7}{16}$	$\frac{5}{16}$	..	18	0.438	0.150
1	1$\frac{1}{16}$	1$\frac{1}{2}$	$\frac{7}{32}$	$\frac{11}{32}$	$\frac{9}{16}$	$\frac{3}{8}$	..	16	0.500	0.170
1$\frac{1}{4}$	1$\frac{5}{16}$	1$\frac{7}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{5}{8}$	$\frac{3}{8}$	..	16	0.500	0.170
1$\frac{1}{2}$	1$\frac{9}{16}$	2$\frac{1}{4}$	$\frac{5}{16}$	$\frac{7}{16}$	$\frac{3}{4}$	$\frac{1}{2}$	..	13	0.625	0.210

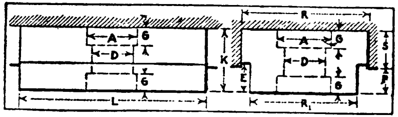


FIG. 6.—Standard Reversible Tongue

TABLE 30.—DIMENSIONS FOR REVERSIBLE TONGUES AND SEATS FOR TWO SIZES OF T BOLTS

Diameter of T-bolt		Tongue Dimensions				Depth of Seat S	Total Thickness Including Tongue K	Height of Shoulder E	Screw Dimensions				
		Width		Length L	Projection P				Diameter of Screw D	Number of Screw	Threads per Inch	Diameter of Head A	Thickness of Head G
Small	Large	R	R										
$\frac{1}{4}$	$\frac{5}{16}$	$\frac{9}{32}$	$\frac{11}{32}$	$\frac{15}{32}$	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{9}{32}$	$\frac{1}{8}$	0.164	8	32	0.260	0.107
$\frac{5}{16}$	$\frac{3}{8}$	$\frac{11}{32}$	$\frac{7}{16}$	$\frac{9}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{5}{16}$	$\frac{9}{64}$	0.190	10	24	0.303	0.124
$\frac{3}{8}$	$\frac{1}{2}$	$\frac{7}{16}$	$\frac{9}{16}$	$\frac{3}{4}$	$\frac{1}{8}$	$\frac{7}{32}$	$\frac{11}{32}$	$\frac{5}{32}$	0.250	..	20	0.375	0.130
$\frac{1}{2}$	$\frac{5}{8}$	$\frac{9}{16}$	$\frac{11}{16}$	$\frac{15}{16}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{5}{32}$	$\frac{1}{4}$	..	20	0.375	0.130
$\frac{5}{8}$	$\frac{3}{4}$	$\frac{11}{16}$	$\frac{13}{16}$	$1\frac{1}{8}$	$\frac{5}{32}$	$\frac{9}{32}$	$\frac{7}{16}$	$\frac{3}{16}$	$\frac{5}{16}$	..	18	0.438	0.150
$\frac{3}{4}$	1	$\frac{13}{16}$	$1\frac{1}{16}$	$1\frac{1}{2}$	$\frac{7}{32}$	$\frac{11}{32}$	$\frac{9}{16}$	$\frac{1}{4}$	$\frac{3}{8}$	..	16	0.500	0.170
1	$1\frac{1}{4}$	$1\frac{1}{16}$	$1\frac{5}{16}$	$1\frac{7}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{5}{8}$	$\frac{9}{32}$	$\frac{3}{8}$	..	16	0.500	0.170
$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{5}{16}$	$1\frac{9}{16}$	$2\frac{1}{4}$	$\frac{5}{16}$	$\frac{7}{16}$	$\frac{3}{4}$	$\frac{11}{32}$	$\frac{1}{2}$	..	13	0.625	0.210

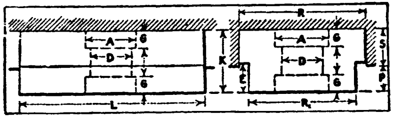


FIG. 7.—Reversible Tongue and Seat

TABLE 31.—DIMENSIONS FOR REVERSIBLE TONGUES AND SEATS FOR T SLOTS OF TWO WIDTHS WITH SAME T BOLT

Diameter of T-bolt	Tongue Dimensions				Depth of Seat S	Total Thickness Including Tongue K	Height of Shoulder E	Screw Dimensions				
	Width		Length L	Projection P				Diameter of Screw D	Number of Screw	Threads per Inch	Diameter of Head A	Thickness of Head G
	R1	R										
$\frac{1}{4}$	$\frac{1}{4}$	$\frac{9}{32}$	$\frac{3}{8}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{7}{32}$	$\frac{3}{32}$	0.125	5	40	0.196	0.081
$\frac{5}{16}$	$\frac{5}{16}$	$\frac{11}{32}$	$\frac{15}{32}$	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{9}{32}$	$\frac{1}{8}$	0.164	8	32	0.260	0.107
$\frac{3}{8}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{9}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{5}{16}$	$\frac{9}{64}$	0.190	10	24	0.303	0.124
$\frac{1}{2}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{3}{4}$	$\frac{1}{8}$	$\frac{7}{32}$	$\frac{11}{32}$	$\frac{5}{32}$	$\frac{1}{4}$	. .	20	0.375	0.130
$\frac{5}{8}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{15}{16}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{5}{32}$	$\frac{1}{4}$	. .	20	0.375	0.130
$\frac{3}{4}$	$\frac{3}{4}$	$\frac{13}{16}$	$1\frac{1}{8}$	$\frac{5}{32}$	$\frac{9}{32}$	$\frac{7}{16}$	$\frac{3}{16}$	$\frac{5}{16}$	. .	18	0.438	0.150
1	1	$1\frac{1}{16}$	$1\frac{1}{2}$	$\frac{7}{32}$	$\frac{11}{32}$	$\frac{9}{16}$	$\frac{1}{4}$	$\frac{3}{8}$	. .	16	0.500	0.170
$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{5}{16}$	$1\frac{7}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{5}{8}$	$\frac{9}{32}$	$\frac{3}{8}$	. .	16	0.500	0.170
$1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{9}{16}$	$2\frac{1}{4}$	$\frac{5}{16}$	$\frac{7}{16}$	$\frac{3}{4}$	$\frac{11}{32}$	$\frac{1}{2}$	. .	13	0.625	0.210

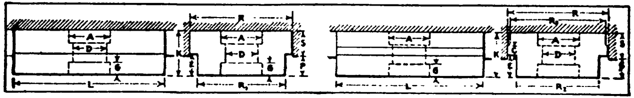


FIG. 8.—Reversible Tongues for Two Widths of T Slots

TABLE 32.—DIMENSIONS FOR REVERSIBLE TONGUES FOR TWO WIDTHS OF T SLOTS

Diameter of of T-bolt		Tongue Dimensions						Depth of Seat S	Total Thickness, Including Tongue K	Height of Shoulder E	Thickness of Land G	Screw Dimensions				
		Width				Length L	Projection P					Diameter of Screw D	Number of Screw	Threads per Inch	Diameter of Head A	Thickness of Head G
Small	Large	R1	R	R3	R2											
$\frac{1}{4}$	$\frac{5}{16}$	$\frac{9}{32}$	$\frac{11}{32}$	$\frac{5}{16}$	$\frac{1}{4}$	$\frac{15}{32}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{5}{16}$	$\frac{1}{8}$	$\frac{1}{16}$	0.164	8	32	0.260	0.107
$\frac{5}{16}$	$\frac{3}{8}$	$\frac{11}{32}$	$\frac{7}{16}$	$\frac{3}{8}$	$\frac{5}{16}$	$\frac{9}{16}$	$\frac{1}{8}$	$\frac{7}{32}$	$\frac{11}{32}$	$\frac{9}{64}$	$\frac{1}{16}$	0.190	10	24	0.303	0.124
$\frac{3}{8}$	$\frac{1}{2}$	$\frac{7}{16}$	$\frac{9}{16}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{3}{4}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{5}{32}$	$\frac{1}{16}$	0.250	..	20	0.375	0.130
$\frac{1}{2}$	$\frac{5}{8}$	$\frac{9}{16}$	$\frac{11}{16}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{15}{16}$	$\frac{1}{8}$	$\frac{9}{32}$	$\frac{13}{32}$	$\frac{5}{32}$	$\frac{3}{32}$	$\frac{1}{4}$	..	20	0.375	0.130
$\frac{5}{8}$	$\frac{3}{4}$	$\frac{11}{16}$	$\frac{13}{16}$	$\frac{3}{4}$	$\frac{5}{8}$	1 $\frac{1}{8}$	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{15}{32}$	$\frac{3}{16}$	$\frac{3}{32}$	$\frac{5}{16}$	..	18	0.438	0.150
$\frac{3}{4}$	1	$\frac{13}{16}$	1 $\frac{1}{16}$	1	$\frac{3}{4}$	1 $\frac{1}{2}$	$\frac{7}{32}$	$\frac{3}{8}$	$\frac{19}{32}$	$\frac{1}{4}$	$\frac{3}{32}$	$\frac{3}{8}$	..	16	0.500	0.170
1	1 $\frac{1}{4}$	1 $\frac{1}{16}$	1 $\frac{5}{16}$	1 $\frac{1}{4}$	1	1 $\frac{7}{8}$	$\frac{1}{4}$	$\frac{7}{16}$	$\frac{11}{16}$	$\frac{9}{32}$	$\frac{1}{8}$	$\frac{3}{8}$	..	16	0.500	0.170
1 $\frac{1}{4}$	1 $\frac{1}{2}$	1 $\frac{5}{16}$	1 $\frac{9}{16}$	1 $\frac{1}{2}$	1 $\frac{1}{4}$	2 $\frac{1}{4}$	$\frac{5}{16}$	$\frac{1}{2}$	$\frac{13}{16}$	$\frac{11}{32}$	$\frac{1}{8}$	$\frac{1}{2}$	..	13	0.625	0.210

driven by the spindle tongues. A collet adapter, which is held in the spindle by a draw-in bolt, is shown at *c*. Adapters *d*, *e*, and *f* are for Nos. 9, 11, and 12 Brown and Sharpe arbors.

TOOLHOLDER SHANKS AND TOOL-POST OPENINGS

Nomenclature for Tool Posts for Lathes, Turret Lathes, Boring Mills, Planers, and Shapers

1a. **Single-Point Tool.**—A single-point tool for turning, planing, and shaping consists of a shank and point. The point may be integral with the shank, tipped with hard metal, or consist of interchangeable bits of cutting material attached to the end of the shank, Fig. 15.

1b. **Toolholder.**—A toolholder is a device for holding a cutting tool in a definite position with respect to the tool slide of a machine tool. Some holders are provided with a means for adjusting the tool point with respect to the center line of the work, whereas others require the use of shims or parallels.

2. **Single-Screw Tool Post.**—The single-screw tool post, as used in most small lathes, Fig. 15, shapers, Fig. 16, and some light planers, consists of a screw, a round post, and a base.

3. **Tool-Post Screw.**—The tool-post screw is fitted in the post. It allows for tool shanks of various sizes and furnishes the means for clamping.

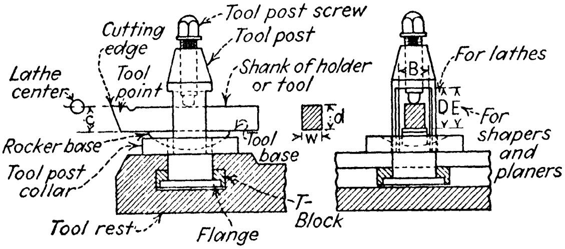


FIG. 15.—Single-Point Tool and Tool Post

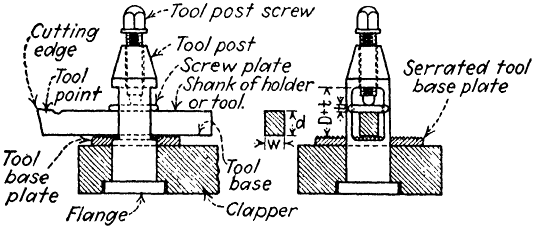


FIG. 16.—Single-Screw Tool Post

4. **Lathe-Tool Post.**—The lathe-tool post carries the screw at one end and an integral circular flange at the other. This flange is recessed in the bottom of a T block fitted into the T slot of the lathe tool rest, Fig. 15.

5a. **Lathe-Tool-Post Collar.**—The lathe-tool-post collar is usually a circular ring fitted about the base of the post. It is sometimes a ring with diametrally spaced steps on the upper face, on which the tool rests. The steps furnish a means for vertical adjustment of the tool point.

5b. **Tool-Post Collar.**—The tool-post collar also may consist of a ring provided with a circular seat on the upper face into which is fitted a rocker base on which the tool rests.

5c. Rocker Base.—The rocker base, Fig. 15, is that part which fits into the circular seat of the tool-post collar. It supports the tool and furnishes a means of adjusting the height of the tool point.

6a. Shaper-Tool-Post Circular Flange.—The shaper-tool-post circular flange, Fig. 16, is recessed into the back face of the clapper and passes through the clapper and a serrated tool-base plate mounted on the face of the clapper, against which the tool base bears.

6b. Screw Plate.—A screw plate is frequently provided for use between the screw and tool shank to distribute the pressure and to prevent damage to the shank, Fig. 16.

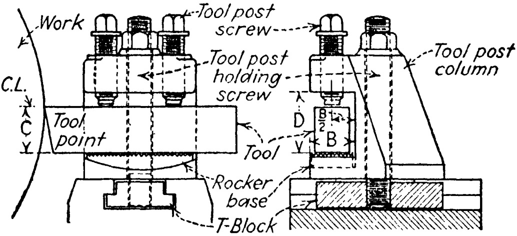


FIG. 17.—Open-Side Tool Post

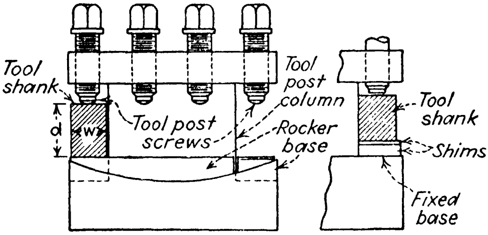


FIG. 18.—Four-Way Tool Post

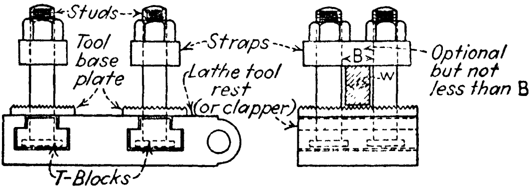


FIG. 19.—T-Bolt Stud Tool Post

7a. Serrated Wedges.—Serrated wedges are sometimes used with square tool posts in screw machines or in open-side tool posts for vertical adjustment of the tools.

7b. Adjustable Collar and Nut.—An adjustable collar and nut fitted about the base of a round tool post is sometimes used in screw machines to provide the vertical adjustment of the tools.

8. Open-Side Tool Post.—The open-side tool post for lathes, Fig. 17, carries one or more binding screws. It may be provided with either a rocker base or flat tool-base plate.

9. Four-Way Turret Tool Post.—The four-way turret tool post used on manufacturing lathes, turret lathes, and vertical boring mills is an indexing. multiple, open-side tool post, Fig. 18.

10a. Strap and Stud Type.—The strap and stud type of toolholder, Fig. 18, is generally fitted on large lathes, boring mills, shapers, slotters, and planers.

10b. Studs.—The studs are fixed to a T block fitted into the T slot of the lathe tool rest or planer clapper, a distance apart indicated as *B* to accommodate the size of tool shanks to be used. The large lathes are provided with two sets of studs.

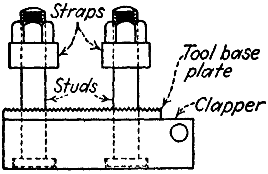


FIG. 20.—Recessed Studs

10c. Strap.—The strap is that member fitted over the studs bearing on the top of the tool shank. The tool rest is supported by the surface of the compound tool rest or on parallels used to provide the vertical adjustment of the tool.

10d. Studs in a Planer.—In a planer, the studs are attached (threaded or recessed) to the face of the clapper, Fig. 20, or in sliding T blocks, Fig. 19, and pass through the serrated tool-base plate against which the tool bears.

TABLE 33.—DIMENSIONS OF TOOL SHANKS, TOOL POST OPENINGS, AND LATHE CENTER HEIGHT

Tool Number	Shank Section Figs. 15 to 19			Lathe Opening Figs. 15 to 19			Planer and Shaper Opening Figs. 15, 16, 19			Lathe Center Height Figs. 15, 17		
	Maximum d	Nominal $d \times w$	Maximum w	Minimum D	Nominal $D \times B$	Minimum B	Minimum E	Nominal $E \times B$	Minimum B	Maximum C	Nominal C	Minimum C
00	0.85	$\frac{3}{4} \times \frac{3}{8}$	0.40	1.27	$1\frac{3}{8} \times \frac{1}{2}$	0.49	1.04	$1\frac{1}{16} \times \frac{1}{2}$	0.49	0.93	$\frac{7}{8}$	0.85
0	0.99	$\frac{7}{8} \times \frac{7}{16}$	0.48	1.48	$1\frac{1}{2} \times \frac{9}{16}$	0.57	1.19	$1\frac{1}{4} \times \frac{9}{16}$	0.57	1.09	1	0.99
1	1.15	$1 \times \frac{1}{2}$	0.56	1.72	$1\frac{3}{4} \times \frac{11}{16}$	0.68	1.38	$1\frac{7}{16} \times \frac{11}{16}$	0.68	1.26	$1\frac{3}{16}$	1.15
2	1.34	$1\frac{1}{4} \times \frac{5}{8}$	0.67	2.00	$2 \times \frac{13}{16}$	0.81	1.61	$1\frac{5}{8} \times \frac{13}{16}$	0.81	1.47	$1\frac{3}{8}$	1.34
3	1.56	$1\frac{1}{2} \times \frac{3}{4}$	0.80	2.34	$2\frac{3}{8} \times 1$	0.96	1.87	$1\frac{7}{8} \times 1$	0.96	1.72	$1\frac{9}{16}$	1.56
4	1.81	$1\frac{3}{4} \times \frac{7}{8}$	0.95	2.71	$2\frac{3}{4} \times 1\frac{3}{16}$	1.14	2.17	$2\frac{3}{16} \times 1\frac{3}{16}$	1.14	1.99	$1\frac{13}{16}$	1.81
5	2.11	2×1	1.13	3.16	$3\frac{1}{8} \times 1\frac{3}{8}$	1.35	2.53	$2\frac{9}{16} \times 1\frac{3}{8}$	1.35	2.32	$2\frac{1}{8}$	2.11
6	2.43	$2\frac{1}{4} \times 1\frac{1}{4}$	1.34	3.65	$3\frac{11}{16} \times 1\frac{5}{8}$	1.61	2.92	$3 \times 1\frac{5}{8}$	1.61	2.67	$2\frac{7}{16}$	2.43
7	2.86	$2\frac{3}{4} \times 1\frac{1}{2}$	1.60	4.29	$4\frac{1}{4} \times 1\frac{7}{8}$	1.91	3.43	$3\frac{7}{16} \times 1\frac{7}{8}$	1.91	3.15	$2\frac{7}{8}$	2.86
8	3.34	$3 \times 1\frac{3}{4}$	1.90	5.00	$5 \times 2\frac{1}{4}$	2.27	4.00	$4 \times 2\frac{1}{4}$	2.27	3.67	$3\frac{3}{8}$	3.34
9	3.87	$3\frac{1}{2} \times 2$	2.26	5.80	$5\frac{3}{4} \times 2\frac{3}{4}$	2.70	4.64	$4\frac{3}{8} \times 2\frac{3}{4}$	2.70	4.25	$3\frac{7}{8}$	3.87
10	4.50	$4\frac{1}{4} \times 2\frac{1}{2}$	2.69	6.75	$6\frac{3}{4} \times 3\frac{1}{4}$	3.21	5.40	$5\frac{1}{2} \times 3\frac{1}{4}$	3.21	4.96	$4\frac{1}{2}$	4.50
11	5.25	5×3	3.20	7.87	$7\frac{7}{8} \times 3\frac{7}{8}$	3.84	6.30	$6\frac{3}{8} \times 3\frac{7}{8}$	3.84	5.77	$5\frac{1}{4}$	5.25

TABLE 34.—DIMENSIONS OF BITS AND SHANKS OF TOOLHOLDERS AND TOOLS
(In Inches)

Square			Rectangular		
Cross-Section	Length	Material	Cross-Section	Length	Material
3/16	⅞,* 1¼, 2, 2½	H	¼ × ⅜	1¾,* 2½	H
¼	⅞,* 1⅝,* 2, 2½	H	¼ × 7/16	1½*	H
¼	2⅛	S	¼† × ½	3, 4, 5, 6, 7, 10	H
¼	5	W	¼ × ¾	1¾*	H
5/16	2¼	T W	5/16 × 7/16	3	H
5/16	1½*	H	5/16 × ½	2½,* 3	H
5/16	2½	H S	5/16 × ⅝	1⅞,* 2*	H
			5/16 × ¾	6	H
			5/16 × 1⅛	2¼*	H
⅜	2½	T W S	⅜ × ½	2½	T
⅜	1¼,* 2,* 3	H	⅜ × ½	3, 4, 6	H
			⅜ × ⅝	4, 5, 6	H
			⅜† × ¾	2¼,* 2½,* 2⅞,* 3¼,* 4, 6, 14	H
			⅜ × ⅞	6	H
			⅜ × 1⅜	1¾*	H
			⅜ × 1½	2¾*	H
7/16	3½	H S	7/16 × ⅞	4¾*	H
½	3½	T W S	½ × 11/16	3¾	H
½	2,* 3,* 4	H	½ × ¾	3½,* 4¾	H
½	4	S	½† × 1	7	T W S
			½ × 1	3½,* 5¼*	H
			½ × 1⅛	3½*	H
			½ × 1⅛	7	H
			½ × 1¼	4½*	H
			½ × 2	3¼*	H
⅝	4	T W S	⅝ × ⅞	5, 6, 7	H
⅝	2¼,* 3,* 4½	H	⅝ × 1	7	S
⅝	4½	S	⅝† × 1¼	8	T W S
			⅝ × 1⅜		H
			⅝ × 1¼	6¼*	H
			⅝ × 1½	6¼*	H
¾	4, 4½, 5	S	¾ × 1	6	H S
¾	4½	W	¾ × 1¼	7½	H
¾	2¾,* 3½,* 5	H	¾† × 1½	9	H T W S
			¾ × 1½	6¼*	H
			¾ × 1⅝		H
⅞	2¼	W	⅞ × 1⅛	7	H
⅞	5	T	⅞† × 1¾	9	S
⅞	5, 6, 7½	S			
⅞	5½, 6½	H			
1	3,* 4,* 5,* 6, 7¼	H	1 × 1¼	7	W S
1	6, 7, 7¼	S	1 × 1¼	9	T
1	7	T W	1 × 1½	10	T W S
1⅛	8	H	1 × 1½	6¼*	H
1¼	7, 8*	T W S H	1† × 2	12	T W S
1½	10	T			
2	12	T			

H indicates high-speed steel; S, stellite; W, tipped tungsten carbide; and T, tantalum carbide.

* Special high-speed steel bits for turret lathes.

† These sizes are given in Table 33.

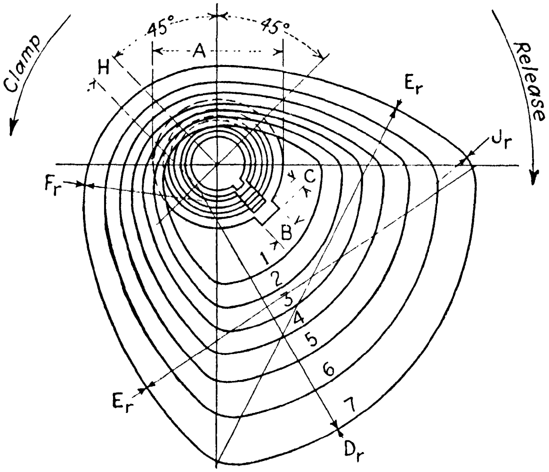
This table includes practically all sizes now marketed. Simplification is desirable, but the results of several recent surveys indicate such a great diversity of sizes that to arrive at fewer standard sizes will require considerable time.

Cam Clamp for Jigs

When properly designed, cams make rapid and effective clamping. The diagram gives the layout; and the table, the dimensions. The second column gives the maximum travel, and the third column, the effective clamping range, which should never be exceeded. In cases of excessive vibration, the *H* dimension should be decreased $\frac{1}{32}$ inch. The pressure exerted by 1 pound on a 1-inch lever is given in column 4, which shows that 1 pound gives 8.4 pounds pressure on a 1-inch lever.

Table 35.—Proportions of Cam Clamps

Clamping devices for jigs and fixtures can be operated by these cams without danger of unlocking. In the table are given the necessary data for cams of different sizes.



No.	Lift 180 Degrees	Clamp 90 Degrees	Ratio 1 Inch Lever	*A*	*B*	*C*	*D*	*E*	*F*	*H*	*J*	Width
1	$\frac{15}{16}$	$\frac{3}{16}$	8.4	$\frac{5}{8}$	$\frac{1}{8}$	$\frac{1}{16}$	$1\frac{5}{16}$	$1\frac{55}{64}$	$\frac{41}{64}$	$\frac{9}{64}$	$\frac{1}{8}$	$\frac{1}{2}$
2	$1\frac{1}{8}$	$\frac{7}{32}$	7.2	$\frac{3}{4}$	$\frac{3}{16}$	$\frac{3}{32}$	$1\frac{9}{16}$	$2\frac{13}{64}$	$\frac{3}{4}$	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{3}{4}$
3	$1\frac{5}{16}$	$\frac{1}{4}$	6.2	$\frac{7}{8}$	$\frac{3}{16}$	$\frac{3}{32}$	$1\frac{13}{16}$	$2\frac{9}{16}$	$\frac{7}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{3}{4}$
4	$1\frac{1}{2}$	$\frac{9}{32}$	5.6	1	$\frac{3}{16}$	$\frac{3}{32}$	$2\frac{1}{16}$	$2\frac{59}{64}$	1	$\frac{7}{32}$	$\frac{5}{16}$	1
5	$1\frac{11}{16}$	$\frac{11}{32}$	4.5	$1\frac{1}{8}$	$\frac{3}{16}$	$\frac{3}{32}$	$2\frac{3}{8}$	$3\frac{23}{64}$	$1\frac{9}{64}$	$\frac{1}{4}$	$\frac{3}{8}$	$1\frac{1}{4}$
6	2	$\frac{3}{8}$	4.2	$1\frac{1}{4}$	$\frac{3}{16}$	$\frac{3}{32}$	$2\frac{3}{4}$	$3\frac{57}{64}$	$1\frac{5}{16}$	$\frac{9}{32}$	$\frac{7}{16}$	$1\frac{1}{2}$
7	$2\frac{3}{8}$	$\frac{15}{32}$	3.3	$1\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{8}$	$3\frac{1}{4}$	$4\frac{19}{32}$	$1\frac{9}{16}$	$\frac{11}{32}$	$\frac{1}{2}$	$1\frac{1}{2}$

AMERICAN STANDARD SHAFTING AND STOCK KEYS

Dimensions and tolerances for plain parallel stock keys, both square and flat, are given in Table 36 and are applicable to shafts up to 6 inches in diameter. These keys shall be cut from cold-finished stock and used without further machining, the dimensions and tolerances given in the table having been fixed with this consideration in mind. These standards were adopted in 1934.

Besides the key dimensions, Table 36 gives the distance from the bottom of the keyseat to the opposite side of the shaft, in order to facilitate gaging for the correct depth of keyseat when machining. This dimension is calculated on the basis of the keyseat's being cut to a depth equal to one-half the height of the key H, and it should be noted that this depth is measured at the side of the keyseat, not in the central plane of the key corresponding to the shaft diameter.

In Table 36, the stock keys are applicable to the general run of work, and the tolerances have been set accordingly. It is understood that these keys are to be cut from cold-finished stock and are to be used without machining. They are not intended to cover the finer applications where a closer fit may be required.

The tolerances in column 4 (Tolerance on W and H) are *negative* and represent the maximum allowable variation *below* the exact nominal size. For example, the standard stock square key for a 2-inch shaft has a maximum size of 0.500 × 0.500 inch and a minimum size of 0.4975 × 0.4975 inch.

AIRCRAFT "TOOL MASTER"

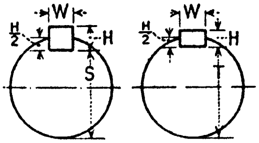
Members of the Aircraft War Production Council of the West Coast, which includes Boeing, Consolidated-Vultee, Douglas, Lockheed, Vega, Northrop, North American, and Ryan, use the following terms for tool masters of different types:

A *tool-master plate* is a two-dimensional authority for contours and locations.

A *tool-master mock-up* is a three-dimensional authority for contoured surfaces.

A tool-master structure is a three-dimensional authority for locations, or locations and contours.

Table 36.—Dimensions of Square and Flat Plain Parallel Stock Keys
(In Inches)
American Standards Association, Oct. 1943



Shaft Diameter	Square Key $W \times H$	Flat Key $W \times H$	Tolerance on W and H (—)	Bottom of Key-seat to Opposite Side of Shaft Square Key S	Bottom of Key-seat to Opposite Side of Shaft Flat Key T
$\frac{1}{2}$	$\frac{1}{8} \times \frac{1}{8}$	$\frac{1}{8} \times \frac{3}{32}$	0.0020	0.430	0.445
$\frac{9}{16}$	$\frac{1}{8} \times \frac{1}{8}$	$\frac{1}{8} \times \frac{3}{32}$	0.0020	0.493	0.509
$\frac{5}{8}$	$\frac{3}{16} \times \frac{3}{16}$	$\frac{3}{16} \times \frac{1}{8}$	0.0020	0.517	0.548
$\frac{11}{16}$	$\frac{3}{16} \times \frac{3}{16}$	$\frac{3}{16} \times \frac{1}{8}$	0.0020	0.581	0.612
$\frac{3}{4}$	$\frac{3}{16} \times \frac{3}{16}$	$\frac{3}{16} \times \frac{1}{8}$	0.0020	0.644	0.676
$\frac{13}{16}$	$\frac{3}{16} \times \frac{3}{16}$	$\frac{3}{16} \times \frac{1}{8}$	0.0020	0.708	0.739
$\frac{7}{8}$	$\frac{3}{16} \times \frac{3}{16}$	$\frac{3}{16} \times \frac{1}{8}$	0.0020	0.771	0.802
$\frac{15}{16}$	$\frac{1}{4} \times \frac{1}{4}$	$\frac{1}{4} \times \frac{3}{16}$	0.0020	0.796	0.827
1	$\frac{1}{4} \times \frac{1}{4}$	$\frac{1}{4} \times \frac{3}{16}$	0.0020	0.859	0.890
$1\frac{1}{16}$	$\frac{1}{4} \times \frac{1}{4}$	$\frac{1}{4} \times \frac{3}{16}$	0.0020	0.923	0.954
$1\frac{1}{8}$	$\frac{1}{4} \times \frac{1}{4}$	$\frac{1}{4} \times \frac{3}{16}$	0.0020	0.986	1.017
$1\frac{3}{16}$	$\frac{1}{4} \times \frac{1}{4}$	$\frac{1}{4} \times \frac{3}{16}$	0.0020	1.049	1.081
$1\frac{1}{4}$	$\frac{1}{4} \times \frac{1}{4}$	$\frac{1}{4} \times \frac{3}{16}$	0.0020	1.112	1.144
$1\frac{5}{16}$	$\frac{5}{16} \times \frac{5}{16}$	$\frac{5}{16} \times \frac{1}{4}$	0.0020	1.137	1.169
$1\frac{3}{8}$	$\frac{5}{16} \times \frac{5}{16}$	$\frac{5}{16} \times \frac{1}{4}$	0.0020	1.201	1.232
$1\frac{7}{16}$	$\frac{3}{8} \times \frac{3}{8}$	$\frac{3}{8} \times \frac{1}{4}$	0.0020	1.225	1.288
$1\frac{1}{2}$	$\frac{3}{8} \times \frac{3}{8}$	$\frac{3}{8} \times \frac{1}{4}$	0.0020	1.289	1.351
$1\frac{9}{16}$	$\frac{3}{8} \times \frac{3}{8}$	$\frac{3}{8} \times \frac{1}{4}$	0.0020	1.352	1.415
$1\frac{5}{8}$	$\frac{3}{8} \times \frac{3}{8}$	$\frac{3}{8} \times \frac{1}{4}$	0.0020	1.416	1.478
$1\frac{11}{16}$	$\frac{3}{8} \times \frac{3}{8}$	$\frac{3}{8} \times \frac{1}{4}$	0.0020	1.479	1.542
$1\frac{3}{4}$	$\frac{3}{8} \times \frac{3}{8}$	$\frac{3}{8} \times \frac{1}{4}$	0.0020	1.542	1.605
$1\frac{13}{16}$	$\frac{1}{2} \times \frac{1}{2}$	$\frac{1}{2} \times \frac{3}{8}$	0.0025	1.527	1.590
$1\frac{7}{8}$	$\frac{1}{2} \times \frac{1}{2}$	$\frac{1}{2} \times \frac{3}{8}$	0.0025	1.591	1.654
$1\frac{15}{16}$	$\frac{1}{2} \times \frac{1}{2}$	$\frac{1}{2} \times \frac{3}{8}$	0.0025	1.655	1.717
2	$\frac{1}{2} \times \frac{1}{2}$	$\frac{1}{2} \times \frac{3}{8}$	0.0025	1.718	1.781
$2\frac{1}{16}$	$\frac{1}{2} \times \frac{1}{2}$	$\frac{1}{2} \times \frac{3}{8}$	0.0025	1.782	1.843
$2\frac{1}{8}$	$\frac{1}{2} \times \frac{1}{2}$	$\frac{1}{2} \times \frac{3}{8}$	0.0025	1.845	1.908
$2\frac{3}{16}$	$\frac{1}{2} \times \frac{1}{2}$	$\frac{1}{2} \times \frac{3}{8}$	0.0025	1.909	1.971
$2\frac{1}{4}$	$\frac{1}{2} \times \frac{1}{2}$	$\frac{1}{2} \times \frac{3}{8}$	0.0025	1.972	2.034
$2\frac{5}{16}$	$\frac{5}{8} \times \frac{5}{8}$	$\frac{5}{8} \times \frac{7}{16}$	0.0025	1.957	2.051
$2\frac{3}{8}$	$\frac{5}{8} \times \frac{5}{8}$	$\frac{5}{8} \times \frac{7}{16}$	0.0025	2.021	2.114
$2\frac{7}{16}$	$\frac{5}{8} \times \frac{5}{8}$	$\frac{5}{8} \times \frac{7}{16}$	0.0025	2.084	2.178
$2\frac{1}{2}$	$\frac{5}{8} \times \frac{5}{8}$	$\frac{5}{8} \times \frac{7}{16}$	0.0025	2.148	2.242
$2\frac{5}{8}$	$\frac{5}{8} \times \frac{5}{8}$	$\frac{5}{8} \times \frac{7}{16}$	0.0025	2.275	2.368
$2\frac{3}{4}$	$\frac{5}{8} \times \frac{5}{8}$	$\frac{5}{8} \times \frac{7}{16}$	0.0025	2.402	2.495
$2\frac{7}{8}$	$\frac{3}{4} \times \frac{3}{4}$	$\frac{3}{4} \times \frac{1}{2}$	0.0025	2.450	2.575
$2\frac{15}{16}$	$\frac{3}{4} \times \frac{3}{4}$	$\frac{3}{4} \times \frac{1}{2}$	0.0025	2.514	2.639
3	$\frac{3}{4} \times \frac{3}{4}$	$\frac{3}{4} \times \frac{1}{2}$	0.0025	2.577	2.702
$3\frac{1}{8}$	$\frac{3}{4} \times \frac{3}{4}$	$\frac{3}{4} \times \frac{1}{2}$	0.0025	2.704	2.829
$3\frac{1}{4}$	$\frac{3}{4} \times \frac{3}{4}$	$\frac{3}{4} \times \frac{1}{2}$	0.0025	2.831	2.956

TABLE 36.—DIMENSIONS OF SQUARE AND FLAT PLAIN PARALLEL STOCK KEYS—*Continued*
(In Inches)

Shaft Diameter	Square Key $W \times H$	Flat Key $W \times H$	Tolerance on W and H (—)	Bottom of Keyseat to Opposite Side of Shaft	
				Square Key S	Flat Key T
$3\frac{3}{8}$	$\frac{7}{8} \times \frac{7}{8}$	$\frac{7}{8} \times \frac{5}{8}$	0.0030	2.880	3.005
$3\frac{7}{16}$	$\frac{7}{8} \times \frac{7}{8}$	$\frac{7}{8} \times \frac{5}{8}$	0.0030	2.944	3.069
$3\frac{1}{2}$	$\frac{7}{8} \times \frac{7}{8}$	$\frac{7}{8} \times \frac{5}{8}$	0.0030	3.007	3.132
$3\frac{5}{8}$	$\frac{7}{8} \times \frac{7}{8}$	$\frac{7}{8} \times \frac{5}{8}$	0.0030	3.140	3.259
$3\frac{3}{4}$	$\frac{7}{8} \times \frac{7}{8}$	$\frac{7}{8} \times \frac{5}{8}$	0.0030	3.261	3.386
$3\frac{7}{8}$	1×1	$1 \times \frac{3}{4}$	0.0030	3.309	3.434
$3\frac{15}{16}$	1×1	$1 \times \frac{3}{4}$	0.0030	3.373	3.498
4	1×1	$1 \times \frac{3}{4}$	0.0030	3.437	3.562
$4\frac{1}{4}$	1×1	$1 \times \frac{3}{4}$	0.0030	3.690	3.815
$4\frac{7}{16}$	1×1	$1 \times \frac{3}{4}$	0.0030	3.881	4.006
$4\frac{1}{2}$	1×1	$1 \times \frac{3}{4}$	0.0030	3.944	4.069
$4\frac{3}{4}$	$1\frac{1}{4} \times 1\frac{1}{4}$	$1\frac{1}{4} \times \frac{7}{8}$	0.0030	4.042	4.229
$4\frac{15}{16}$	$1\frac{1}{4} \times 1\frac{1}{4}$	$1\frac{1}{4} \times \frac{7}{8}$	0.0030	4.232	4.420
5	$1\frac{1}{4} \times 1\frac{1}{4}$	$1\frac{1}{4} \times \frac{7}{8}$	0.0030	4.296	4.483
$5\frac{1}{4}$	$1\frac{1}{4} \times 1\frac{1}{4}$	$1\frac{1}{4} \times \frac{7}{8}$	0.0030	4.550	4.733
$5\frac{7}{16}$	$1\frac{1}{4} \times 1\frac{1}{4}$	$1\frac{1}{4} \times \frac{7}{8}$	0.0030	4.740	4.927
$5\frac{1}{2}$	$1\frac{1}{4} \times 1\frac{1}{4}$	$1\frac{1}{4} \times \frac{7}{8}$	0.0030	4.803	4.991
$5\frac{3}{4}$	$1\frac{1}{2} \times 1\frac{1}{2}$	$1\frac{1}{2} \times 1$	0.0030	4.900	5.150
$5\frac{15}{16}$	$1\frac{1}{2} \times 1\frac{1}{2}$	$1\frac{1}{2} \times 1$	0.0030	5.091	5.341
6	$1\frac{1}{2} \times 1\frac{1}{2}$	$1\frac{1}{2} \times 1$	0.0030	5.155	5.405

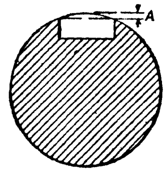
TABLE 37.—DIMENSIONS OF LARGE PLAIN PARALLEL STOCK KEYS*

$W \times H$	Tolerance*,† on W and H (—)	$W \times H$	Tolerance*,† on W and H (—)
$1\frac{3}{4} \times 1\frac{1}{4}$	0.0040	$3\frac{1}{2} \times 2\frac{1}{2}$	0.0050
$2 \times 1\frac{1}{2}$	0.0040	4×3	0.0050
$2\frac{1}{2} \times 1\frac{3}{4}$	0.0040	$5 \times 3\frac{1}{2}$	0.0050
3×2	0.0040	6×4	0.0050

---

* Stock keys are applicable to the general run of work and the tolerances have been set accordingly. They are not intended to cover the finer applications where a closer fit may be required.

† These tolerances are *negative* and represent the maximum allowable variation *below* the exact nominal size. For example, for the standard 3- by 2-inch key the maximum size is 3.000 × 2.000 inches, and the minimum size is 2.996 × 1.996 inches.



Formula: $A = \frac{1}{2}(D - \sqrt{D^2 - W^2})$.
D = shaft diameter. W = width of keyway.
EXAMPLE.—$\frac{5}{8}$-inch keyway in $1\frac{11}{16}$-inch shaft
$A = \frac{1}{2}(1.6875 - \sqrt{2.845 - 0.390})$
$= \frac{1}{2}(1.687 - 1.566)$
$= 0.060$ inch.

TABLE 38.—FINDING TOTAL KEYWAY DEPTH

In the column marked "Size of Shaft" find the number representing the size; then to the right find the column representing the keyway to be cut and the decimal there is the distance A, which added to the depth of the keyway will give the total depth from the point where the cutter first begins to cut.

Size of Shaft	¼	$\frac{5}{16}$	⅜	$\frac{7}{16}$	½
	Keyway	Keyway	Keyway	Keyway	Keyway
½	0.0325	....	....	....	....
$\frac{9}{16}$	0.0289	....	....	....	....
⅝	0.0254	0.0413	....	....	....
$\frac{11}{16}$	0.0236	0.0379	....	....	....
¾	0.022	0.0346	0.0511	....	....
$\frac{13}{16}$	0.0198	0.0314	0.0465	....	....
⅞	0.0177	0.0283	0.042	0.0583	....
$\frac{15}{16}$	0.0164	0.0264	0.0392	0.0544	....
1	0.0152	0.0246	0.0365	0.0506	0.067
1 $\frac{1}{16}$	0.0143	0.0228	0.0342	0.0476	0.0625
1⅛	0.0136	0.021	0.0319	0.0446	0.0581
1 $\frac{3}{16}$	0.0131	0.0204	0.0304	0.0421	0.0551
1¼	0.0127	0.0198	0.029	0.0397	0.0522
1 $\frac{5}{16}$	0.0123	0.0191	0.0279	0.038	0.0499
1⅜	0.012	0.0185	0.0268	0.0364	0.0477
1 $\frac{7}{16}$	0.0114	0.0174	0.0254	0.0346	0.0453
1½	0.011	0.0164	0.024	0.0328	0.0429
1 $\frac{9}{16}$	0.0107	0.0158	0.0231	0.0309	0.0412
1⅝	0.0105	0.0153	0.0221	0.0291	0.0395
1 $\frac{11}{16}$	0.0102	0.0147	0.0214	0.0282	0.0383
1¾	0.0099	0.0142	0.0207	0.0274	0.0371
1 $\frac{13}{16}$	0.0095	0.0136	0.0198	0.0265	0.0355
1⅞	0.0093	0.013	0.019	0.0257	0.0339
1 $\frac{15}{16}$	0.009	0.0127	0.0184	0.025	0.0328
2	0.0088	0.0124	0.0179	0.0243	0.0317
2 $\frac{1}{16}$	0.0083	0.0117	0.0173	0.0236	0.0308
2⅛	0.0078	0.0111	0.0168	0.0229	0.0299
2 $\frac{3}{16}$	0.0073	0.0109	0.0163	0.0222	0.0291
2¼	0.007	0.0107	0.0159	0.0216	0.0282
2 $\frac{5}{16}$	0.0068	0.0104	0.0155	0.0209	0.0274
2⅜	0.0066	0.0102	0.0152	0.0202	0.0267
2 $\frac{7}{16}$	0.0064	0.01	0.0149	0.0198	0.026
2½	0.0063	0.0098	0.0146	0.0194	0.0253

Pratt & Whitney, Round End Keys

The length "L" may vary from the table given, but must at least be equal to (2 × W). The maximum length of slot is (4" + W). Note that the width (W) is in all cases equal to the depth (D).

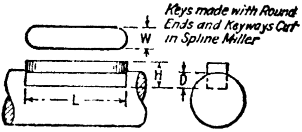


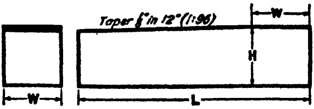
TABLE 39.—PRATT & WHITNEY KEY SYSTEM

Key No.	L	W	H	D	Key No.	L	W	H	D
1	1/2	1/16	3/32	1/16	22	1 3/8	1/4	3/8	1/4
2		3/32	9/64	3/32	23		5/16	15/32	5/16
3		1/8	3/16	1/8	F		3/8	9/16	3/8
4	5/8	3/32	9/64	3/32	24	1 1/2	1/4	3/8	1/4
5		1/8	3/16	1/8	25		5/16	15/32	5/16
6		5/32	15/64	5/32	G		3/8	9/16	3/8
7	3/4	1/8	3/16	1/8	51	1 3/4	1/4	3/8	1/4
8		5/32	15/64	5/32	52		5/16	15/32	5/16
9		3/16	9/32	3/16	53		3/8	9/16	3/8
10	7/8	5/32	15/64	5/32	26	2	3/16	9/32	3/16
11		3/16	9/32	3/16	27		1/4	3/8	1/4
12		7/32	21/64	7/32	28		5/16	15/32	5/16
A		1/4	3/8	1/4	29		3/8	9/16	3/8
13	1	3/16	9/32	3/16	54	2 1/4	1/4	3/8	1/4
14		7/32	21/64	7/32	55		5/16	15/32	5/16
15		1/4	3/8	1/4	56		3/8	9/16	3/8
B		5/16	15/32	5/16	57		7/16	21/32	7/16
16	1 1/8	3/16	9/32	3/16	58	2 1/2	5/16	15/32	5/16
17		7/32	21/64	7/32	59		3/8	9/16	3/8
18		1/4	3/8	1/4	60		7/16	21/32	7/16
C		5/16	15/32	5/16	61		1/2	3/4	1/2
19	1 1/4	3/16	9/32	3/16	30	3	3/8	9/16	3/8
20		7/32	21/64	7/32	31		7/16	21/32	7/16
21		1/4	3/8	1/4	32		1/2	3/4	1/2
D		5/16	15/32	5/16	33		9/16	27/32	9/16
E		3/8	9/16	3/8	34		5/8	15/16	5/8

Plain Taper Stock Keys, Square and Flat

Adopted by Am. Stand. Asso., Oct., 1943 American Standard, February, 1927

TABLE 40.—DIMENSIONS AND TOLERANCES



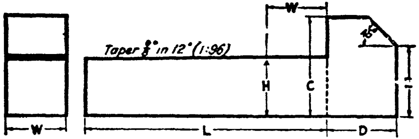
Diameters of Shafts	Square Type		Flat Type		Tolerances on Keys	
	Maximum Width	Height at Large End[1]	Maximum Width	Height at Large End[1]	Width	Height
(Inclusive)	W	H	W	H	(Minus)	(Plus)
½ to $\frac{9}{16}$	⅛	⅛	⅛	$\frac{3}{32}$	0.0020	0.0020
⅝ to ⅞	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{3}{16}$	⅛	0.0020	0.0020
$\frac{15}{16}$ to 1¼	¼	¼	¼	$\frac{3}{16}$	0.0020	0.0020
1$\frac{5}{16}$ to 1¾	⅜	⅜	⅜	¼	0.0020	0.0020
1$\frac{13}{16}$ to 2¼	½	½	½	⅜	0.0025	0.0025
2$\frac{5}{16}$ to 2¾	⅝	⅝	⅝	$\frac{7}{16}$	0.0025	0.0025
2⅞ to 3¼	¾	¾	¾	½	0.0025	0.0025
3⅜ to 3¾	⅞	⅞	⅞	⅝	0.0030	0.0030
3⅞ to 4½	1	1	1	¾	0.0030	0.0030
4¾ to 5½	1¼	1¼	1¼	⅞	0.0030	0.0030
5¾ to 6	1½	1½	1½	1	0.0030	0.0030

TABLE 41.—STOCK LENGTHS OF PLAIN TAPER STOCK KEYS

Shaft Diameter, (Inclusive)	Length of Key,* L						.
½ – $\frac{9}{16}$	½	¾	1	1¼	1½	1¾	2
⅝ – ⅞	¾	1⅛	1½	1⅞	2¼	2⅝	3
$\frac{15}{16}$–1¼	1	1½	2	2½	3	3½	4
1$\frac{5}{16}$–1⅜	1¼	1⅞	2½	3⅛	3¾	4½	5¼
1$\frac{7}{16}$–1¾	1½	2¼	3	3¾	4½	5¼	6
1$\frac{13}{16}$–2¼	2	3	4	5	6	7	8
2$\frac{5}{16}$–2¾	2½	3¾	5	6¼	7½	8¾	10
2⅞ –3¼	3	4½	6	7½	9	10½	12
3⅜ –3¾	3½	5¼	7	8¾	10½	12¼	14
3⅞ –4½	4	6	8	10	12	14	16
4¾ –5½	5	7½	10	12½	15	17½	20
5¾ –6	6	9	12	15	18	21	24

* The minimum stock length of keys is equal to four times the key width, and the maximum stock length is equal to sixteen times the key width. The increments of increase in length are equal to twice the width.

Gib-Head Taper Stock Keys, Square and Flat



Approved as Tentative American Standard, February, 1927

TABLE 42.—DIMENSIONS AND TOLERANCES

Diameters of Shafts	Square Type					Flat Type					Tolerances on Keys	
	Key		Gib Head			Key		Gib Head				
(Inclusive)	Maximum Width W	Height at Large End[1] H	Height C	Length D	Height Edge of Chamfer E	Maximum Width W	Height at Large End[1] H	Height C	Length D	Height Edge of Chamfer E	Width (Minus)	Height (Plus)
1/2 to 9/16	1/8	1/8	1/4	7/32	5/32	1/8	3/32	3/16	1/8	1/8	0.0020	0.0020
5/8 to 7/8	3/16	3/16	5/16	9/32	7/32	3/16	1/8	1/4	3/16	5/32	0.0020	0.0020
15/16 to 1 1/4	1/4	1/4	7/16	11/32	11/32	1/4	3/16	5/16	1/4	3/16	0.0020	0.0020
1 5/16 to 1 3/4	3/8	3/8	11/16	15/32	15/32	3/8	1/4	7/16	3/8	5/16	0.0020	0.0020
1 13/16 to 2 1/4	1/2	1/2	7/8	19/32	5/8	1/2	3/8	5/8	1/2	7/16	0.0025	0.0025
2 5/16 to 2 3/4	5/8	5/8	1 1/16	23/32	3/4	5/8	7/16	3/4	5/8	1/2	0.0025	0.0025
2 7/8 to 3 1/4	3/4	3/4	1 1/4	7/8	7/8	3/4	1/2	7/8	3/4	5/8	0.0025	0.0025
3 3/8 to 3 3/4	7/8	7/8	1 1/2	1	1	7/8	5/8	1 1/16	7/8	3/4	0.0030	0.0030
3 7/8 to 4 1/2	1	1	1 3/4	1 3/16	1 3/16	1	3/4	1 1/4	1	13/16	0.0030	0.0030
4 3/4 to 5 1/2	1 1/4	1 1/4	2	1 7/16	1 7/16	1 1/4	7/8	1 1/2	1 1/4	1	0.0030	0.0030
5 3/4 to 6	1 1/2	1 1/2	2 1/2	1 3/4	1 3/4	1 1/2	1	1 3/4	1 1/2	1 1/4	0.0030	0.0030

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[1] This heigth of the key is measured at the distance W from the gib head. For length see Table 3.

TABLE 43.—COLD-FINISHED SHAFTING, STANDARD DIAMETERS AND LENGTHS

Adopted by American Standards Association, October, 1943.

Diameters and Tolerances

Transmission Shafting Sizes in Inches	Machinery Shafting Sizes in Inches	Tolerances[1] on Diameters (−) in Inches	Transmission Shafting Sizes in Inches	Machinery Shafting Sizes in Inches	Tolerances[1] on Diameters (−) in Inches
	1/2	0.002	2 3/16	2 3/16	0.004
	9/16	0.002		2 1/4	0.004
	5/8	0.002		2 5/16	0.004
	11/16	0.002		2 3/8	0.004
	3/4	0.002	2 7/16	2 7/16	0.004
	13/16	0.002		2 1/2	0.004
	7/8	0.002		2 5/8	0.004
15/16	15/16	0.002		2 3/4	0.004
	1	0.002		2 7/8	0.004
	1 1/16	0.003	2 15/16	3	0.004
	1 1/8	0.003		3 1/8	0.004
1 3/16	1 3/16	0.003		3 1/4	0.004
	1 1/4	0.003		3 3/8	0.004
	1 5/16	0.003	3 7/16	3 1/2	0.004
	1 3/8	0.003		3 5/8	0.004
1 7/16	1 7/16	0.003		3 3/4	0.004
	1 1/2	0.003		3 7/8	0.004
	1 9/16	0.003	3 15/16	4	0.004
	1 5/8	0.003		4 1/4	0.005
1 11/16	1 11/16	0.003	4 7/16	4 1/2	0.005
	1 3/4	0.003		4 3/4	0.005
	1 13/16	0.003	4 15/16	5	0.005
	1 7/8	0.003		5 1/4	0.005
1 15/16	1 15/16	0.003	5 7/16	5 1/2	0.005
	2	0.003		5 3/4	0.005
	2 1/16	0.004	5 15/16	6	0.005
	2 1/8	0.004			

[1] NOTE.—These tolerances are *negative* and represent the maximum allowable variation *below* the exact nominal size. For instance, the maximum diameter of the 1 15/16-inch shaft is 1.938 inch and its minimum allowable diameter is 1.935 inch.

Standard stock lengths for cold-finished shafting shall be 16, 20 and 24 feet.

Ground Steel Shafting

Ground shafting is used in many parts of machine building. On Cumberland shafting, which has been ground since about 1880, the tolerances on shafts 2 7/16 inches and smaller is from basic to 0.002 inch undersize. Shafts from 2 1/2 to 8 inches are undersize from basic to 0.003 inch. It can also be obtained 0.0005 oversize to 0.0005 inch undersize, and from basic to 0.0005 inch under. The shafts can be supplied up to 60 feet long and within 0.0025 inch of straightness. Ground shafting will frequently save much time where it can be used.

A.G.M.A. STANDARD KEYWAYS FOR HOLES IN GEARS

The August, 1937, revision of the "Recommended Practice of the American Gear Manufacturers Association for Standard Keyways for Holes in Gears" provides an enlarged and revised table of keyways for holes in gears and key-stock sizes.

Keyways are to be cut from exact nominal size to plus 0.002 inch in width, and the depth shall be nominal to plus $\frac{1}{64}$ inch for straight keys. For taper keys, the depth shall be from nominal to $\frac{1}{64}$ inch minus. For heat-treated pinions, the depth shall be $\frac{1}{32}$ inch minus 0 to plus $\frac{1}{64}$ inch over nominal size within $\frac{1}{32}$-inch *R* in corners of the keyway.

It is understood that these keys are to be cut from cold-finished stock and are to be used without machining, as this A.G.M.A. standard is for general industrial practice. The keystock is to be cold-rolled steel 0.10 to 0.20 carbon.

TABLE 44.—KEYWAYS IN GEAR HUBS

Diameter of Holes Inclusive	Standard Keyways		Key Stock	Special Keyways		Key Stock
	Width	Depth		Width	Depth	
$\frac{5}{16}$ to $\frac{7}{16}$	$\frac{3}{32}$	$\frac{3}{64}$	$\frac{3}{32} \times \frac{3}{32}$			
$\frac{1}{2}$ to $\frac{9}{16}$	$\frac{1}{8}$	$\frac{1}{16}$	$\frac{1}{8} \times \frac{1}{8}$	$\frac{1}{8}$	$\frac{3}{64}$	$\frac{1}{8} \times \frac{3}{32}$
$\frac{5}{8}$ to $\frac{7}{8}$	$\frac{3}{16}$	$\frac{3}{32}$	$\frac{3}{16} \times \frac{3}{16}$	$\frac{3}{16}$	$\frac{1}{16}$	$\frac{3}{16} \times \frac{1}{8}$
$\frac{15}{16}$ to $1\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{1}{4} \times \frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{32}$	$\frac{1}{4} \times \frac{3}{16}$
$1\frac{5}{16}$ to $1\frac{3}{8}$	$\frac{5}{16}$	$\frac{5}{32}$	$\frac{5}{16} \times \frac{5}{16}$	$\frac{5}{16}$	$\frac{3}{32}$	$\frac{5}{16} \times \frac{1}{4}$
$1\frac{7}{16}$ to $1\frac{3}{4}$	$\frac{3}{8}$	$\frac{3}{16}$	$\frac{3}{8} \times \frac{3}{8}$	$\frac{3}{8}$	$\frac{1}{8}$	$\frac{3}{8} \times \frac{1}{4}$
$1\frac{13}{16}$ to $2\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{2} \times \frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{16}$	$\frac{1}{2} \times \frac{3}{8}$
$2\frac{5}{16}$ to $2\frac{3}{4}$	$\frac{5}{8}$	$\frac{5}{16}$	$\frac{5}{8} \times \frac{5}{8}$	$\frac{5}{8}$	$\frac{7}{32}$	$\frac{5}{8} \times \frac{7}{16}$
$2\frac{13}{16}$ to $3\frac{1}{4}$	$\frac{3}{4}$	$\frac{3}{8}$	$\frac{3}{4} \times \frac{3}{4}$	$\frac{3}{4}$	$\frac{1}{4}$	$\frac{3}{4} \times \frac{1}{2}$
$3\frac{5}{16}$ to $3\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{16}$	$\frac{7}{8} \times \frac{7}{8}$	$\frac{7}{8}$	$\frac{5}{16}$	$\frac{7}{8} \times \frac{5}{8}$
$3\frac{13}{16}$ to $4\frac{1}{2}$	1	$\frac{1}{2}$	1×1	1	$\frac{3}{8}$	$1 \times \frac{3}{4}$
$4\frac{9}{16}$ to $5\frac{1}{2}$	$1\frac{1}{4}$	$\frac{7}{16}$	$1\frac{1}{4} \times \frac{7}{8}$			
$5\frac{9}{16}$ to $6\frac{1}{2}$	$1\frac{1}{2}$	$\frac{1}{2}$	$1\frac{1}{2} \times 1$			
$6\frac{9}{16}$ to $7\frac{1}{2}$	$1\frac{3}{4}$	$\frac{5}{8}$	$1\frac{3}{4} \times 1\frac{1}{8}$			
$7\frac{9}{16}$ to $8\frac{15}{16}$	2	$\frac{3}{4}$	$2 \times 1\frac{3}{8}$			
9 to $10\frac{15}{16}$	$2\frac{1}{2}$	$\frac{7}{8}$	$2\frac{1}{2} \times 1\frac{5}{8}$			
11 to $12\frac{15}{16}$	3	1	3×2			
13 to $14\frac{15}{16}$	$3\frac{1}{2}$	$1\frac{1}{4}$	$3\frac{1}{2} \times 2\frac{3}{8}$			
15 to $17\frac{15}{16}$	4	$1\frac{1}{2}$	$4 \times 2\frac{3}{4}$			
18 to 21	5	$1\frac{3}{4}$	$5 \times 3\frac{1}{4}$			

Keystock is to vary from the exact nominal size in width and thickness to a negative tolerance as follows:

Keys $\frac{3}{32}$ *to* $\frac{3}{8}$ inch square, inclusive, −0.002
Keys $\frac{1}{2}$ to $\frac{3}{4}$ inch square, inclusive, −0.0025
Keys $\frac{7}{8}$ to $1\frac{1}{2}$ by 1 square, inclusive, −0.003
Keys $1\frac{3}{4}$ by $1\frac{1}{8}$ to 3 by 2 square, inclusive, −0.004
Keys $3\frac{1}{2}$ by $2\frac{3}{8}$ to 5 by $3\frac{1}{4}$ square, inclusive, −0.005

WOODRUFF KEYS, KEY SLOTS, AND CUTTER STANDARDS APPROVED BY THE AMERICAN STANDARD ASSOCIATION, DECEMBER, 1930

The standardization of Woodruff Keys was undertaken with a view to establishing a logical and simplified series to replace, with the least possible disturbance, the several individual standards in use, thus permitting interchangeability of keys made by different manufacturers and eliminating, as far as possible, the special or little-used sizes.

The most suitable type of key-slot cutter was selected and a rational indexing system adopted whereby both keys and cutters can be classified and referred to by number. This system of "key numbers" is explained in Footnote 1 of Tables 45 to 47.

Keys

The keys included in this standard range from $\frac{1}{16}$ inch wide by $\frac{1}{2}$ inch long to $\frac{3}{8}$ inch wide by $1\frac{1}{2}$ inches long. Table 45, which covers both the round- and the flat-bottom types as optional designs, gives the over-all dimensions. The maximum and minimum limits indicated for the key width are such that, when assembled with the key slot whose width and tolerances are given in Table 46, the assembly can be made without distortion of the shaft or the necessity of individual fitting when the maximum key is inserted in the minimum key slot, and also, without shake, when the minimum key is inserted in the maximum key slot. Such interchangeability is of particular value in facilitating mass production and the application of the keys. For more particular work, however, the specified fit may be obtained by gaging the finished key slot and selecting by measurement the key required. Breaking the corners of the key with a 0.010-inch radius is optional but sharp edges should be removed from all finished keys.

In addition to the dimensions of the key, Table 45 gives the distance "E" from the center of the circle forming the key profile to the top of the key in order to facilitate the layout in the drafting room.

Key Slots

Table 46 gives the over-all dimensions with maximum and minimum limits for key slots corresponding to the series of keys established. It will be noted that the depth "h" is measured from the sharp edge of the slot, not from the shaft circumference on the center line of the key and, therefore, does not indicate the depth to which the cutter should be fed into the shaft. This amount varies with the shaft diameter, and Table 45 will be found very useful.

The amount by which the key, when in place, will extend from the shaft may be determined by subtracting the key-slot depth "h" (Table 46) from the height of key C (Table 45).

Key-Slot Cutters

Two series of key-slot cutters, fine and coarse teeth, both of the shank type and having a shank diameter of $\frac{1}{2}$ inch for all sizes, have

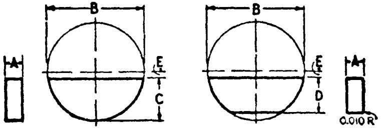


TABLE 45.—WOODRUFF KEY DIMENSIONS

Key[1] Number	Nominal Key Size	Width of Key		Diameter of Key		Height of Key				Distance below Center
		A		B		C		D		
	A by B	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	E
204	$\frac{1}{16}$ by $\frac{1}{2}$	0.0635	0.0625	0.500	0.490	0.203	0.198	0.194	0.188	$\frac{3}{64}$
304	$\frac{3}{32}$ by $\frac{1}{2}$	0.0948	0.0938	0.500	0.490	0.203	0.198	0.194	0.188	$\frac{3}{64}$
305	$\frac{3}{32}$ by $\frac{5}{8}$	0.0948	0.0938	0.625	0.615	0.250	0.245	0.240	0.234	$\frac{1}{16}$
404	$\frac{1}{8}$ by $\frac{1}{2}$	0.1260	0.1250	0.500	0.490	0.203	0.198	0.194	0.188	$\frac{3}{64}$
405	$\frac{1}{8}$ by $\frac{5}{8}$	0.1260	0.1250	0.625	0.615	0.250	0.245	0.240	0.234	$\frac{1}{16}$
406	$\frac{1}{8}$ by $\frac{3}{4}$	0.1260	0.1250	0.750	0.740	0.313	0.308	0.303	0.297	$\frac{1}{16}$
505	$\frac{5}{32}$ by $\frac{5}{8}$	0.1573	0.1563	0.625	0.615	0.250	0.245	0.240	0.234	$\frac{1}{16}$
506	$\frac{5}{32}$ by $\frac{3}{4}$	0.1573	0.1563	0.750	0.740	0.313	0.308	0.303	0.297	$\frac{1}{16}$
507	$\frac{5}{32}$ by $\frac{7}{8}$	0.1573	0.1563	0.875	0.865	0.375	0.370	0.365	0.359	$\frac{1}{16}$

606	$\frac{3}{16}$ by $\frac{3}{4}$	0.1885	0.1875	0.750	0.740	0.313	0.308	0.303	0.297	$\frac{1}{16}$
607	$\frac{3}{16}$ by $\frac{7}{8}$	0.1885	0.1875	0.875	0.865	0.375	0.370	0.365	0.359	$\frac{1}{16}$
608	$\frac{3}{16}$ by 1	0.1885	0.1875	1.000	0.990	0.438	0.433	0.428	0.422	$\frac{1}{16}$
609	$\frac{3}{16}$ by $1\frac{1}{8}$	0.1885	0.1875	1.125	1.115	0.484	0.479	0.475	0.469	$\frac{5}{64}$
807	$\frac{1}{4}$ by $\frac{7}{8}$	0.2510	0.2500	0.875	0.865	0.375	0.370	0.365	0.359	$\frac{1}{16}$
808	$\frac{1}{4}$ by 1	0.2510	0.2500	1.000	0.990	0.438	0.433	0.428	0.422	$\frac{1}{16}$
809	$\frac{1}{4}$ by $1\frac{1}{8}$	0.2510	0.2500	1.125	1.115	0.484	0.479	0.475	0.469	$\frac{5}{64}$
810	$\frac{1}{4}$ by $1\frac{1}{4}$	0.2510	0.2500	1.250	1.240	0.547	0.542	0.537	0.531	$\frac{5}{64}$
811	$\frac{1}{4}$ by $1\frac{3}{8}$	0.2510	0.2500	1.375	1.365	0.594	0.589	0.584	0.578	$\frac{3}{32}$
812	$\frac{1}{4}$ by $1\frac{1}{2}$	0.2510	0.2500	1.500	1.490	0.641	0.636	0.631	0.625	$\frac{7}{64}$
1008	$\frac{5}{16}$ by 1	0.3135	0.3125	1.000	0.990	0.438	0.433	0.428	0.422	$\frac{1}{16}$
1009	$\frac{5}{16}$ by $1\frac{1}{8}$	0.3135	0.3125	1.125	1.115	0.484	0.479	0.475	0.469	$\frac{5}{64}$
1010	$\frac{5}{16}$ by $1\frac{1}{4}$	0.3135	0.3125	1.250	1.240	0.547	0.542	0.537	0.531	$\frac{5}{64}$
1011	$\frac{5}{16}$ by $1\frac{3}{8}$	0.3135	0.3125	1.375	1.365	0.594	0.489	0.584	0.578	$\frac{3}{32}$
1012	$\frac{5}{16}$ by $1\frac{1}{2}$	0.3135	0.3125	1.500	1.490	0.641	0.636	0.631	0.625	$\frac{7}{64}$
1210	$\frac{3}{8}$ by $1\frac{1}{4}$	0.3760	0.3750	1.250	1.240	0.547	0.542	0.537	0.531	$\frac{5}{64}$
1211	$\frac{3}{8}$ by $1\frac{3}{8}$	0.3760	0.3750	1.375	1.365	0.594	0.589	0.584	0.578	$\frac{3}{32}$
1212	$\frac{3}{8}$ by $1\frac{1}{2}$	0.3760	0.3750	1.500	1.490	0.641	0.636	0.631	0.625	$\frac{7}{64}$

All dimensions given in inches.

[1] Key numbers indicate the nominal key dimensions. The last two digits give the nominal diameter B in eighths of an inch and the digits preceding the last two give the nominal width A in thirty-seconds of an inch Thus, 204 indicates a key $\frac{2}{32}$ by $\frac{4}{8}$ or $\frac{1}{16}$ by $\frac{1}{2}$ inches; 1210 indicates a key $\frac{12}{32}$ by $\frac{10}{8}$ or $\frac{3}{8}$ by $1\frac{1}{4}$ inches.

been adopted as best suited to the requirements. The key numbers established to designate the size of key apply also to the corresponding cutters. The over-all dimensions, number of teeth for both fine and coarse series, tolerances, and general design features, are given in Table 47.

It should be noted that a back clearance of 0.006 to 0.010 inch per inch (20 to 40 minutes of arc) shall be ground on each side of the cutter and that each side face may be recessed to a depth of not more than one-quarter of the cutter width.

The accuracy in grinding shall be such that the cutting edges of the teeth will be concentric within 0.002 inch and both sides will be parallel within 0.0005-inch indicator reading.

In order that the cutters may be centered accurately for regrinding, provision for which has been made in the maximum dimensions (Note 2, Table 47), both ends of the shank shall be drilled and countersunk with a 60-degree angle in accordance with the following:

Key Number	Maximum Countersink Diameter	Drill Diameter	Depth of Drilled Hole below Countersink
402	$\frac{3}{32}$	$\frac{1}{16}$	$\frac{1}{16}$
403 to 708	$\frac{1}{8}$	$\frac{1}{16}$	$\frac{1}{16}$
806 to 1,212	$\frac{3}{16}$	$\frac{3}{32}$	$\frac{3}{32}$

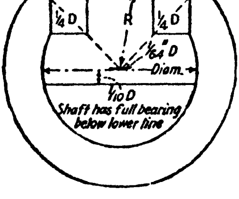
All dimensions given in inches.

All cutters shall be marked on the shank with the key number or nominal size and the maker's name or trade mark.

The S.A.E. and General Motors Standards conform to the cutter dimension given in Table 47 but use different key numbers and add center drill dimensions. Gage dimensions for key slots are the same as for maximum and minimum of keys in Table 45.

THE KENNEDY KEY

This key was designed by Julian Kennedy of Pittsburgh, Pa., and is used in heavy work such as gearing for rolling mills. The keys are square and one-fourth the diameter, the sides being parallel and a good fit, and the top of the key is tapered $\frac{1}{8}$ inch per foot. The keys are set so that lines drawn diagonally through the corners will meet at the center of the shaft. After boring, the hub is offset one-sixty-fourth the diameter and rebored to the same radius, relieving the top of the bore. This relieves the sides so that the full bearing usually begins at one-tenth the diameter below the center, as shown. Up to 6-inch shafts, single keys are generally used; above 6 inches. the two keys as shown.



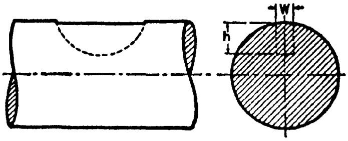


TABLE 46.—DIMENSIONS FOR KEY SLOT

Key[1] Number	Nominal Key Size	Key Slot			
		Width W		Depth h	
	A by B	Maximum	Minimum	Maximum	Minimum
204	1/16 by 1/2	0.0630	0.0615	0.1718	0.1668
304	3/32 by 1/2	0.0943	0.0928	0.1561	0.1511
305	3/32 by 5/8	0.0943	0.0928	0.2031	0.1981
404	1/8 by 1/2	0.1255	0.1240	0.1405	0.1355
405	1/8 by 5/8	0.1255	0.1240	0.1875	0.1825
406	1/8 by 3/4	0.1255	0.1240	0.2505	0.2455
505	5/32 by 5/8	0.1568	0.1553	0.1719	0.1669
506	5/32 by 3/4	0.1568	0.1553	0.2349	0.2299
507	5/32 by 7/8	0.1568	0.1553	0.2969	0.2919
606	3/16 by 3/4	0.1880	0.1863	0.2193	0.2143
607	3/16 by 7/8	0.1880	0 1863	0.2813	0.2763
608	3/16 by 1	0.1880	0.1863	0.3443	0.3393
609	3/16 by 1 1/8	0.1880	0.1863	0.3903	0.3853
807	1/4 by 7/8	0.2505	0.2487	0.2500	0.2450
808	1/4 by 1	0.2505	0.2487	0.3130	0.3080
809	1/4 by 1 1/8	0.2505	0.2487	0.3590	0.3540
810	1/4 by 1 1/4	0.2505	0.2487	0.4220	0.4170
811	1/4 by 1 3/8	0.2505	0.2487	0.4690	0.4640
812	1/4 by 1 1/2	0.2505	0.2487	0.5160	0.5110
1008	5/16 by 1	0.3130	0.3111	0.2818	0.2768
1009	5/16 by 1 1/8	0.3130	0.3111	0.3278	0.3228
1010	5/16 by 1 1/4	0.3130	0.3111	0.3908	0.3858
1011	5/16 by 1 3/8	0.3130	0.3111	0.4378	0.4328
1012	5/16 by 1 1/2	0.3130	0.3111	0.4848	0.4798
1210	3/8 by 1 1/4	0.3755	0.3735	0.3595	0.3545
1211	3/8 by 1 3/8	0.3755	0.3735	0.4065	0.4015
1212	3/8 by 1 1/2	0.3755	0.3735	0.4535	0.4485

All dimensions given in inches.

[1] Key numbers indicate the nominal key dimensions. The last two digits give the nominal diameter B in eighths of an inch and the digits preceding the last two give the nominal width A in thirty-seconds of an inch. Thus, 204 indicates a key 2/32 by 4/8 or 1/16 by 1/2 inches. 1210 indicates a key 12/32 by 10/8 or 3/8 by 1 1/4 inches.

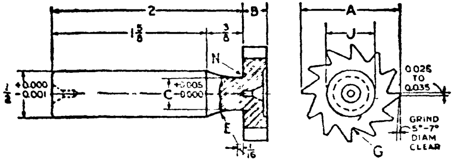


TABLE 47.—WOODRUFF KEY-SLOT CUTTER DIMENSIONS

Key[1] Number	Nominal Key Size	Number of Teeth		Cutter[2] Diameter A		Cutter[3] Width B		Neck Diameter		Radii				Recess Diameter
		Fine	Coarse	Maximum	Minimum	Maximum	Minimum	C	C[4]	E	E[4]	G	N	J
204	$\frac{1}{16}$ by $\frac{1}{2}$	10	8	0.515	0.510	0.0625	0.0620	0.130	.....	$\frac{21}{64}$	....	$\frac{1}{64}$	$\frac{1}{64}$	$\frac{1}{4}$
304	$\frac{3}{32}$ by $\frac{1}{2}$	10	8	0.515	0.510	0.0938	0.0933	0.160	.....	$\frac{3}{8}$	....	$\frac{1}{64}$	$\frac{1}{64}$	$\frac{1}{4}$
305	$\frac{3}{32}$ by $\frac{5}{8}$	10	8	0.640	0.635	0.0938	0.0933	0.191	.....	$\frac{13}{32}$	....	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{5}{16}$
404	$\frac{1}{8}$ by $\frac{1}{2}$	10	8	0.515	0.510	0.1250	0.1245	0.191	.....	$\frac{13}{32}$	....	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{1}{4}$
405	$\frac{1}{8}$ by $\frac{5}{8}$	10	8	0.640	0.635	0.1250	0.1245	0.223	.....	$\frac{7}{16}$	....	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{5}{16}$
406	$\frac{1}{8}$ by $\frac{3}{4}$	10	8	0.765	0.760	0.1250	0.1245	0.217	.....	$\frac{13}{32}$	....	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{3}{8}$
505	$\frac{5}{32}$ by $\frac{5}{8}$	10	8	0.640	0.635	0.1563	0.1558	0.253	.....	$\frac{15}{32}$	....	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{5}{16}$
506	$\frac{5}{32}$ by $\frac{3}{4}$	10	8	0.765	0.760	0.1563	0.1558	0.247	.....	$\frac{7}{16}$	....	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{3}{8}$
507	$\frac{5}{32}$ by $\frac{7}{8}$	12	9	0.892	0.887	0.1563	0.1558	0.247	.....	$\frac{7}{16}$	....	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{7}{16}$
606	$\frac{3}{16}$ by $\frac{3}{4}$	10	8	0.765	0.760	0.1873	0.1868	0.279	.....	$\frac{1}{2}$	....	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{3}{8}$
607	$\frac{3}{16}$ by $\frac{7}{8}$	12	9	0.892	0.887	0.1873	0.1868	0.279	.....	$\frac{1}{2}$	....	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{7}{16}$
608	$\frac{3}{16}$ by 1	12	10	1.017	1.012	0.1873	0.1868	0.279	.....	$\frac{1}{2}$	....	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{1}{2}$
609	$\frac{3}{16}$ by $1\frac{1}{8}$	12	10	1.142	1.137	0.1873	0.1868	0.312	.....	$\frac{9}{16}$	....	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{9}{16}$

807	$\frac{1}{4}$ by $\frac{7}{8}$	12	9	0.892	0.887	0.2497	0.2492	0.342	.....	$\frac{21}{32}$	....	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{7}{16}$
808	$\frac{1}{4}$ by 1	12	10	1.017	1.012	0.2497	0.2492	0.342	.....	$\frac{21}{32}$	....	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{1}{2}$
809	$\frac{1}{4}$ by $1\frac{1}{8}$	12	10	1.142	1.137	0.2497	0.2492	0.373	.....	$\frac{3}{4}$	....	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{9}{16}$
810	$\frac{1}{4}$ by $1\frac{1}{4}$	14	10	1.270	1.265	0.2497	0.2492	0.373	.....	$\frac{3}{4}$	.	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{5}{8}$
811	$\frac{1}{4}$ by $1\frac{3}{8}$	14	10	1.395	1.390	0.2497	0.2492	.....	0.401	...	$\frac{3}{64}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{11}{16}$
812	$\frac{1}{4}$ by $1\frac{1}{2}$	16	12	1.520	1.515	0.2497	0.2492	.....	0.435	....	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{3}{4}$
1008	$\frac{5}{16}$ by 1	12	10	1.017	1.012	0.3121	0.3116	.....	0.401	....	$\frac{3}{64}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{2}$
1009	$\frac{5}{16}$ by $1\frac{1}{8}$	12	10	1.142	1.137	0.3121	0.3116	.....	0.435	....	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{9}{16}$
1010	$\frac{5}{16}$ by $1\frac{1}{4}$	14	10	1.270	1.265	0.3121	0.3116	.....	0.435	....	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{5}{8}$
1011	$\frac{5}{16}$ by $1\frac{3}{8}$	14	10	1.395	1.390	0.3121	0.3116	.....	0.467	....	$\frac{1}{64}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{11}{16}$
1012	$\frac{5}{16}$ by $1\frac{1}{2}$	16	12	1.520	1.515	0.3121	0.3116	.....	0.467	....	$\frac{1}{64}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{3}{4}$
1210	$\frac{3}{8}$ by $1\frac{1}{4}$	14	10	1.270	1.265	0.3745	0.3740	.....	0.467	....	$\frac{1}{64}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{5}{8}$
1211	$\frac{3}{8}$ by $1\frac{3}{8}$	14	10	1.395	1.390	0.3745	0.3740	.....	0.467	....	$\frac{1}{64}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{11}{16}$
1212	$\frac{3}{8}$ by $1\frac{1}{2}$	16	12	1.520	1.515	0.3745	0.3740	.....	0.467	....	$\frac{1}{64}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{3}{4}$

All dimensions given in inches.

[1] Key numbers indicate the nominal key dimensions. The last two digits give the nominal diameter B in eighths of an inch, and the digits preceding the last two give the nominal width A in thirty-seconds of an inch. Thus, 204 indicates a key $\frac{2}{32}$ by $\frac{4}{8}$ or $\frac{1}{16}$ by $\frac{1}{2}$ inch; 1210 indicates a key $\frac{12}{32}$ by $\frac{10}{8}$ or $\frac{3}{8}$ by $1\frac{1}{4}$ inches.

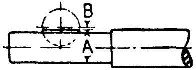
[2] The maximum diameters of cutters given in Table 3 will permit regrinding once or twice, depending on the widths.

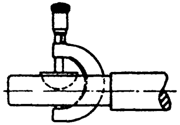
[3] The minimum cutter width is equal to the minimum key-slot width plus 0.0005 inch. The width of the key-slot cut by the maximum cutter will be found in the majority of cases to be slightly less than the maximum key-slot width given in Table 46.

[4] For keys larger than No. 810, cutters with cylindrical necks are specified, in which case E is the small radius between the cylindrical neck and shank.

TABLE 48.—SELECTION AND INSPECTION OF WOODRUFF KEYS[1]

Key Circles and Cutter Diameters	B	Key Widths																	
		1/16	3/32	1/8	5/32	3/16	1/4	5/16	3/8	7/16	1/2	5/8	3/4	7/8	1	1 1/4	1 1/2	1 3/4	2
1/2	3/64	204	304	404															
5/8	1/16		305	405	505														
3/4	1/16			406	506	606													
7/8	1/16				507	607	807												
1	1/16					608	808	1008											
1 1/8	5/64					609	809	1009											
1 1/4	5/64	Key numbers					810	1010	1210										
1 3/8	3/32						811	1011	1211										
1 1/2	7/64						812	1012	1212										
	1/2	0.530	0.544	0.554															
9/16			0.605	0.617															
5/8			0.668	0.681	0.693														
11/16			0.731	0.744	0.756														
3/4			0.793	0.807	0.819	0.831													
13/16				0.870	0.883	0.895													
7/8				0.933	0.946	0.958													
15/16				0.995	1.009	1.021													
	1			1.058	1.071	1.084	1.110												
1 1/16					1.134	1.147	1.173												
1 1/8					1.197	1.210	1.237												
1 3/16					1.260	1.273	1.299												





		1 1/4					1.323	1.336	1.363	1.387											
1 5/16								1.339	1.425	1.450											
	1 3/8							1.462	1.488	1.513											
1 7/16								1.525	1.551	1.576											
			1 1/2					1.587	1.614	1.640	1.663										
1 9/16									1.677	1.704	1.727										
	1 5/8								1.740	1.766	1.790										
1 11/16									1.802	1.830	1.854										
		1 3/4							1.866	1.892	1.917	1.941									
1 13/16									1.928	1.955	1.981	2.005									
	1 7/8								1.991	2.018	2.043	2.068									
1 15/16									2.053	2.081	2.107	2.131									
			2						2.117	2.144	2.170	2.194	2.219								
2 1/16									2.180	2.207	2.223	2.258	2.282								
	2 1/8								2.243	2.270	2.296	2.321	2.346								
2 3/16									2.305	2.333	2.359	2.384	2.408								
		2 1/4							2.368	2.396	2.422	2.447	2.472								
2 5/16									2.431	2.458	2.485	2.511	2.535								
	2 3/8				Shaft diameters				2.494	2.521	2.547	2.573	2.599								
2 7/16									2.556	2.583	2.611	2.637	2.661								
			2 1/2						2.619	2.647	2.678	2.700	2.725	2.772							
	2 5/8								2.744	2.772	2.800	2.825	2.851	2.899							
		2 3/4							2.870	2.898	2.924	2.951	2.977	3.026							
	2 7/8								2.995	3.023	3.050	3.077	3.103	3.153							
			3						3.120	3.148	3.176	3.202	3.229	3.279	3.327						
	3 1/8								3.245	3.274	3.301	3.328	3.355	3.405	3.454						
		3 1/4							3.371	3.399	3.426	3.454	3.481	3.532	3.581						
	3 3/8								3.496	3.524	3.552	3.580	3.607	3.660	3.707						

Dimension *A* is important to the shop when milling shafting for Woodruff and square keys. Optimum key width is equal to one-quarter the shaft diameter. Shafting and key sizes are American standards, except that between ⅜- and ¾-inch widths the Woodruff keys are available, but not standard. to use chart: Locate the shaft diameter in the left-hand column. Read across to column for the desired key width. At this point will be found dimension *A*, which should be added to the shop drawing. Col. *B* gives dimensions shown in upper cut.

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[1] Joseph H. Roberts & Associates, Inc.

TABLE 48.—SELECTION AND INSPECTION OF WOODRUFF KEYS.[1]—*Continued*

Key Circles and Cutter Diameters			*B*	Key Widths																	
				1/16	3/32	1/8	5/32	3/16	1/4	5/16	3/8	7/16	1/2	5/8	3/4	7/8	1	1¼	1½	1¾	2
			3½						3.621	3.649	3.678	3.705	3.732	3.784	3.834	3.881					
	3⅝								3.746	3.775	3.802	3.830	3.858	3.910	3.960	4.010					
		3¾							3.871	3.900	3.928	3.956	3.984	4.036	4.087	4.135					
	3⅞								3.996	4.025	4.053	4.081	4.109	4.162	4.213	4.262					
			4						4.121	4.150	4.178	4.206	4.234	4.287	4.339	4.389	4.436				
		4¼								4.400	4.429	4.457	4.585	4.539	4.591	4.641	4.690				
			4½							4.650	4.679	4.708	4.736	4.790	4.843	4.894	4.943				
		4¾								4.900	4.930	4.958	4.986	5.041	5.095	5.146	5.196				
			5							5.151	5.180	5.209	5.237	5.292	5.346	5.398	5.449	5.545			
		5¼									5.430	5.459	5.486	5.543	5.598	5.650	5.702	5.799			
			5½								5.681	5.710	5.738	5.794	5.849	5.902	5.954	6.053			
		5¾									5.931	5.960	5.989	6.045	6.104	6.154	6.206	6.306			
			6								6.181	6.210	6.239	6.296	6.351	6.405	6.459	6.559	6.654		
		6¼										6.461	6.490	6.546	6.602	6.656	6.789	6.811	6.908		
			6½									6.711	6.741	6.797	6.853	6.907	6.961	7.064	7.162		
		6¾										6.961	6.990	7.048	7.104	7.159	7.212	7.316	7.415		
			7									7.211	7.241	7.298	7.355	7.410	7.464	7.569	7.668	7.764	
		7¼											7.491	7.549	7.605	7.661	7.715	7.820	7.921	8.017	
			7½										7.741	7.799	7.856	7.911	7.966	8.074	8.174	8.271	
		7¾											7.991	8.049	8.106	8.162	8.217	8.324	8.426	8.525	
			8										8.242	8.300	8.357	8.413	8.469	8.575	8.679	8.778	8.873

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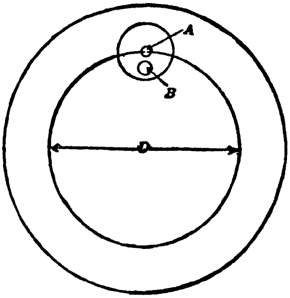
[1] Joseph H. Roberts & Associates, Inc.

THE NORDBERG KEY



The Nordberg key is round with a taper of $\frac{1}{16}$ inch per foot. The large diameter is approximately one-fourth the diameter of the shaft, up to 6 inches. Above this the key is about one-fifth the shaft diameter. In practice, the small hole *A* is first drilled at the joint, then a hole *B*, as large as convenient without exceeding the key diameter. This prevents the full-size drill from "running," or crowding, into the cast iron of the hub.

SPLINES

Splined Shafts for Machine Use

Although splined shafts were developed largely for use in automobile construction, they have become standard machine elements that are used in many other classes of machines. Standards were first developed by the S.A.E. in connection with different motor-car builders. Clearances depend on the kind of work they are to do, whether the parts are to have a permanent fit or to slide, and if so, whether under load or not. The tables give the latest practice. Dimensions apply only to soft-broached holes which permit the tolerances given to be easily maintained. The formula for torque capacity under each table is in inch-pounds per inch of bearing length and at 1,000 pounds pressure per square inch.

Formula for Finding Root Width of Splineways

The following formula will be found useful for calculating the root width of splineways on splined shafts:

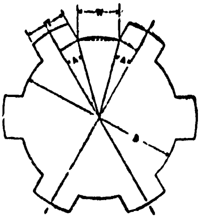
$$\sin\left(\frac{\frac{360^\circ}{N} - 2A}{2}\right) \times B = W$$

in which N = number of splines.
B = diameter of shaft at the root of the splineway.

Angle A must first be computed as follows:

$$\sin A = \frac{T}{2} \div \frac{B}{2}, \text{ or } \sin A = \frac{T}{B}$$

in which T = width of spline.
B = diameter of shaft at root of splineway.
D = largest inside diameter.
d = smallest inside diameter.
W = width of splined recess.
h = height of tooth or $\frac{1}{2}(D - d)$.



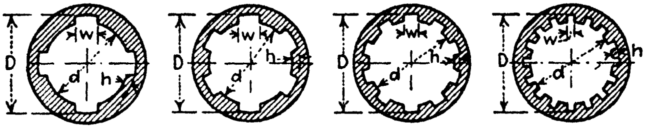


TABLE 49.—FORMULAS FOR *W*, *h*, AND *d*, IN TERMS OF LARGE DIAMETER *D*
(In Inches)

No. of Splines	*W*, for All Fits	*A* Permanent Fit		*B* To Slide, Not under Load		*C* To Slide under Load	
		h	*d*	*h*	*d*	*h*	*d*
4	0.241*D**	0.075*D*	0.850*D*	0.125*D*	0.750*D*		
6	0.250*D*	0.050*D*	0.900*D*	0.075*D*	0.850*D*	0.100*D*	0.800*D*
10	0.156*D*	0.045*D*	0.910*D*	0.070*D*	0.860*D*	0.095*D*	0.810*D*
16	0.098*D*	0.045*D*	0.910*D*	0.070*D*	0.850*D*	0.095*D*	0.810*D*

Radii on corners of splines not to exceed 0.015 inch.

Splines shall not be more than 0.006 inch per foot out of parallel with respect to the axis of the shaft.

No allowance is made for radii on corners or for clearance. Dimensions are intended to apply to only the soft-broached hole. Allowance must be made for machining.

* Four splines, for fits *A* and *B* only.

TABLE 50.—FOUR-SPLINE FITTINGS
(In Inches)

Nom. Diam.	For All Fits				4A Permanent Fit					4B To Slide When Not under Load				
	D		W		d		h		T*	d		h		T*
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.		Min.	Max.	Min.	Max.	
$\frac{3}{4}$	0.749	0.750	0.179	0.181	0.636	0.637	0.055	0.056	78	0.561	0.562	0.093	0.094	123
$\frac{7}{8}$	0.874	0.875	0.209	0.211	0.743	0.744	0.065	0.066	107	0.655	0.656	0.108	0.109	167
1	0.999	1.000	0.239	0.241	0.849	0.850	0.074	0.075	139	0.749	0.750	0.124	0.125	219
$1\frac{1}{8}$	1.124	1.125	0.269	0.271	0.955	0.956	0.083	0.084	175	0.843	0.844	0.140	0.141	277
$1\frac{1}{4}$	1.249	1.250	0.299	0.301	1.061	1.062	0.093	0.094	217	0.936	0.937	0.155	0.156	341
$1\frac{3}{8}$	1.374	1.375	0.329	0.331	1.168	1.169	0.102	0.103	262	1.030	1.031	0.171	0.172	414
$1\frac{1}{2}$	1.499	1.500	0.359	0.361	1.274	1.275	0.111	0.112	311	1.124	1.125	0.186	0.187	491
$1\frac{5}{8}$	1.624	1.625	0.389	0.391	1.380	1.381	0.121	0.122	367	1.218	1.219	0.202	0.203	577
$1\frac{3}{4}$	1.749	1.750	0.420	0.422	1.486	1.487	0.130	0.131	424	1.311	1.312	0.218	0.219	670
2	1.998	2.000	0.479	0 482	1.698	1.700	0.148	0.150	555	1.498	1.500	0.248	0.250	875
$2\frac{1}{4}$	2.248	2.250	0.539	0.542	1.910	1.912	0.167	0.169	703	1.685	1.687	0.279	0.281	1,106
$2\frac{1}{2}$	2.498	2.500	0.599	0.602	2.123	2.125	0.185	0.187	865	1.873	1.875	0.310	0.312	1,365
3	2.998	3.000	0.720	0.723	2.548	2.550	0.223	0.225	1,249	2.248	2.250	0.373	0.375	1,969

* Torque = 1,000 × 4 × mean radius × h × L.

TABLE 51.—SIX-SPLINE FITTINGS
(In Inches)

Nom. Diam.	For All Fits				6*A* Permanent Fit			6*B* To Slide When Not under Load			6*C* To Slide When under Load		
	D		*W*		*d*		*T**	*d*		*T**	*d*		*T**
	Min.	Max.	Min.	Max.	Min.	Max.		Min.	Max.		Min.	Max.	
$\frac{3}{4}$	0.749	0.750	0.186	0.188	0.674	0.675	80	0.637	0.638	117	0.599	0.600	152
$\frac{7}{8}$	0.874	0.875	0.217	0.219	0.787	0.788	109	0.743	0.744	159	0.699	0.700	207
1	0.999	1.000	0.248	0.250	0.899	0.900	143	0.849	0.850	208	0.799	0.800	270
1$\frac{1}{8}$	1.124	1.125	0.279	0.281	1.012	1.013	180	0.955	0.956	263	0.899	0.900	342
1$\frac{1}{4}$	1.249	1.250	0.311	0.313	1.124	1.125	223	1.062	1.063	325	0.999	1.000	421
1$\frac{3}{8}$	1.374	1.375	0.342	0.344	1.237	1.238	269	1.168	1.169	393	1.099	1.100	510
1$\frac{1}{2}$	1.499	1.500	0.373	0.375	1.349	1.350	321	1.274	1.275	468	1.199	1.200	608
1$\frac{5}{8}$	1.624	1.625	0.404	0.406	1.462	1.463	376	1.380	1.381	550	1.299	1.300	713
1$\frac{3}{4}$	1.749	1.750	0.436	0.438	1.574	1.575	436	1.487	1.488	637	1.399	1.400	827
2	1.998	2.000	0.497	0.500	1.798	1.800	570	1.698	1.700	833	1.598	1.600	1,080
2$\frac{1}{4}$	2.248	2.250	0.560	0.563	2.023	2.025	721	1.911	1.913	1,052	1.798	1.800	1,367
2$\frac{1}{2}$	2.498	2.500	0.622	0.625	2.248	2.250	891	2.123	2.125	1,300	1.998	2.000	1,688
3	2.998	3.000	0.747	0.750	2.698	2.700	1,283	2.548	2.550	1,873	2.398	2.400	2,430

* Torque = 1,000 × 6 × mean rad. × h × L.

TABLE 52.—TEN-SPLINE FITTINGS
(In Inches)

Nom. Diam.	For All Fits				10*A* Permanent Fit			10*B* To Slide When Not under Load			10*C* To Slide When under Load		
	D		*W*		*d*		*T**	*d*		*T**	*d*		*T**
	Min.	Max.	Min.	Max.	Min.	Max.		Min.	Max.		Min.	Max.	
3/4	0.749	0.750	0.115	0.117	0.682	0.683	120	0.644	0.645	183	0.607	0.608	241
7/8	0.874	0.875	0.135	0.137	0.795	0.796	165	0.752	0.753	248	0.708	0.709	329
1	0.999	1.000	0.154	0.156	0.909	0.910	215	0.859	0.860	326	0.809	0.810	430
1 1/8	1.124	1.125	0.174	0.176	1.023	1.024	271	0.967	0.968	412	0.910	0.911	545
1 1/4	1.249	1.250	0.193	0.195	1.137	1.138	336	1.074	1.075	508	1.012	1.013	672
1 3/8	1.374	1.375	0.213	0.215	1.250	1.251	406	1.182	1.183	614	1.113	1.114	813
1 1/2	1.499	1.500	0.232	0.234	1.364	1.365	483	1.289	1.290	732	1.214	1.215	967
1 5/8	1.624	1.625	0.252	0.254	1.478	1.479	566	1.397	1.398	860	1.315	1.316	1,135
1 3/4	1.749	1.750	0.271	0.273	1.592	1.593	658	1.504	1.505	997	1.417	1.418	1,316
2	1.998	2.000	0.309	0.312	1.818	1.820	860	1.718	1.720	1,302	1.618	1.620	1,720
2 1/4	2.248	2.250	0.348	0.351	2.040	2.048	1,088	1.933	1.935	1,647	1.821	1.823	2,176
2 1/2	2.498	2.500	0.387	0.390	2.273	2.275	1,343	2.148	2.150	2,034	2.023	2.025	2,688
3	2.998	3.000	0.465	0.468	2.728	2.730	1,934	2.578	2.580	2,929	2.428	2.430	3,869
3 1/2	3.497	3.500	0.543	0.546	3.182	3.185	2,632	3.007	3.010	3,987	2.832	2.835	5,266
4	3.997	4.000	0.621	0.624	3.637	3.640	3,438	3.437	3.440	5,208	3.237	3.240	6,878
4 1/2	4.497	4.500	0.699	0.702	4.092	4.095	4,351	3.867	3.870	6,591	3.642	3.645	8,705
5	4.997	5.000	0.777	0.780	4.547	4.550	5,371	4.297	4.300	8,137	4.047	4.050	10,746
5 1/2	5.497	5.500	0.855	0.858	5.002	5.005	6,500	4.727	4.730	9,846	4.452	4.455	13,003
6	5.997	6.000	0.933	0.936	5.457	5.460	7,735	5.157	5.160	11,718	4.857	4.860	15,475

* Torque = 1,000 × 10 × mean radius × h × L.

TABLE 53.—SIXTEEN-SPLINE FITTINGS (In Inches)

Nom. Diam.	For All Fits				16*A* Permanent Fit			16*B* To Slide When Not under Load			16*C* To Slide When under Load		
	D		*W*		*d*		*T**	*d*		*T**	*d*		*T**
	Min.	Max.	Min.	Max.	Min.	Max.		Min.	Max.		Min.	Max.	
2	1.997	2.000	0.193	0.196	1.817	1.820	1,375	1.717	1.720	2,083	1.617	1.620	2,751
2½	2.497	2.500	0.242	0.245	2.273	2.275	2,149	2.147	2.150	3,255	2.022	2.025	4,299
3	2.997	3.000	0.291	0.294	2.727	2.730	3,094	2.577	2.580	4,687	2.427	2.430	6,190
3½	3.497	3.500	0.340	0.343	3.182	3.185	4,212	3.007	3.010	6,378	2.832	2.835	8,426
4	3.997	4.000	0.389	0.392	3.637	3.640	5,501	3.437	3.440	8,333	3.237	3.240	11,005
4½	4.497	4.500	0.438	0.441	4.092	4.095	6,962	3.867	3.870	10,546	3.642	3.645	13,928
5	4.997	5.000	0.487	0.490	4.547	4.550	8,595	4.297	4.300	13,020	4.047	4.050	17,195
5½	5.497	5.500	0.536	0.539	5.002	5.005	10,395	4.727	4.730	15,754	4.452	4.455	20,806
6	5.997	6.000	0.585	0.588	5.547	5.460	12,377	5.157	5.150	18,749	4.857	4.860	24,760

NOTE.—Tables 49 to 53, report of Broaches Division, adopted by the Society of Automotive Engineers, January, 1914; revised by Shaft Fittings Division, March, 1920; checked for current use, January, 1936.

* Torque = 1,000 × 16 × mean radius × h × L.

INVOLUTE SPLINES

The advantages of splines with involute sides, instead of the straight-sided splines formerly used, led to the formation of an engineering committee representing both the American Society of Mechanical Engineers and the Society of Automotive Engineers to standardize this form of spline. After many meetings and careful consideration from a variety of angles, the standards from which the tables in the following pages have been taken were finally adopted in December, 1944.

The splines shown and the sizes finally adopted are especially designed for use on automotive parts, for machine tools, and for general use where straight-sided splines were formerly used. Experience has shown that the 30-degree pressure angle has advantages for all-round use and gives best results for a wide variety of machine design.

Involute splines can be measured with pins, in the same way as gears, but allowance must be made for the class of fit, material, heat-treatment, accuracy of spacing, and contour.

Spline design is frequently controlled by the antifriction bearings used on the splined shaft. The bores of these bearings, which are in metric measurement, form the basis for size ranges covered by the standards given. So the spline sizes are designated by the symbols used in bearing practice.

The basic formulas are

INVOLUTE SPLINES

Circular pitch $= \dfrac{3.1416}{\text{diametral pitch*}}$	Pitch diameter $= \dfrac{\text{No. of teeth}}{\text{diametral pitch*}}$
Addendum = dedendum $= \dfrac{0.500}{\text{diametral pitch*}}$	Major diameter $= \dfrac{\text{No. of teeth} + 1}{\text{diametral pitch*}}$
Circular tooth thickness $= \dfrac{1.5708}{\text{diametral pitch*}}$	Minor diameter $= \dfrac{\text{No. of teeth} - 1}{\text{diametral pitch*}}$

* Diametral pitch referred to is that which controls the diameter, such as 8, in $\frac{8}{16}$.

There are three types of fits:

1. On the major diameter, where fit is controlled by varying the major diameter of the external.

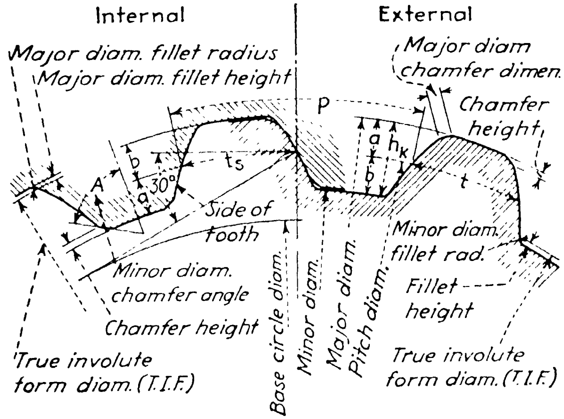

Internal
External
Major diam. fillet radius
Major diam. fillet height
Major diam chamfer dimen.
Chamfer height
p
A
b
a
30°
t_s
a
h_k
b
t
Side of tooth
Minor diam. chamfer angle
Chamfer height
True involute form diam. (T.I.F.)
Base circle diam.
Minor diam.
Major diam.
Pitch diam.
Minor diam. fillet rad.
Fillet height
True involute form diam. (T.I.F.)

FIG. 21.—Spline-Tooth Nomenclature.

P	Diametral Pitch	D	Pitch Diameter
p	Circular Pitch	D_b	Base Circle Diameter
a	Addendum	D_o	Major Diameter
b	Dedendum	D_R	Minor Diameter
h_k	Working Depth	T.I.F.	Diameter at Junction of Involute Form with Fillet
c	Clearance		
t	Circular Tooth Thickness	d_x	Measuring Pin Diameter—External
t_s	Circular Space Width	d_n	Measuring Pin Diameter—Internal
φ	Pressure Angle	C	Measurement over Pins—External
N	Number of Teeth	G	Measurement over Pins—Internal

Pressure Angle = 30 degrees

2. On the sides of the teeth, where fit is controlled by varying tooth thickness.

3. On the minor diameter, where fit is controlled by varying the minor diameter of the internal.[1]

The three methods, which are tabulated below, are each divided into three classes, for sliding, locating, and press applications.

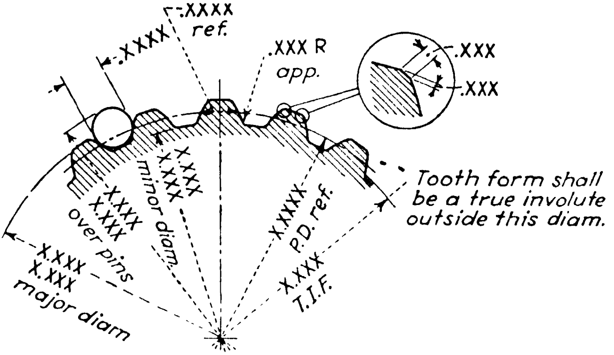


FIG. 22

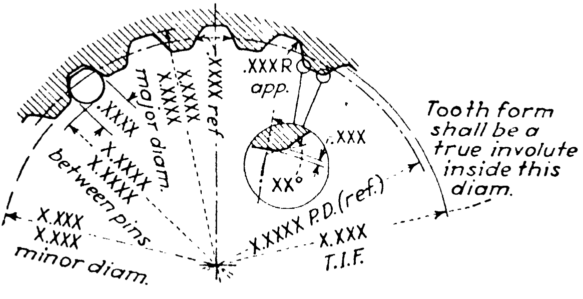


FIG. 23.

Involute Spline Data for Figs. 22 and 23.

XX	Teeth
XX/XX	Diametral Pitch
XX°	Pressure Angle
.XXXX	Maximum Permissible Error in Involute Profile
.XXXX	Maximum Cumulative Error in Spacing

The above data shall be given for internal and external splines

Sliding fits must have clearance at all points, the location fit must be close at one point, and the press fit must involve an interference at only one point. By using Table 54 as a key to the appropriate table the correct combinations of dimensions may be selected for any desired fit. For all classes of fits the internal major diameter and measurement between pins should be selected from column 4 and column 11, respectively, in Tables 58 and 59.

---

[1] Requires special tooling.

TABLE 54.—CLASSES OF FITS

Fit on	Type of Fit	Class of Fit	Internal			External		
			Major Diameter	Minor Diameter	Betw. Pins	Major Diameter	Minor Diameter	Over Pins
Major diameter	Sliding	I	Col. 4	Col. 5	Col. 11	Col. 22	Col. 16	Col. 26
	Location	II	Col. 4	Col. 5	Col. 11	Col. 23	Col. 16	Col. 26
	Press	III	Col. 4	Col. 5	Col. 11	Col. 24	Col. 16	Col. 26
Sides of teeth	Sliding	A	Col. 4	Col. 5	Col. 11	Col. 22	Col. 16	Col. 26
	Location	B	Col. 4	Col. 5	Col. 11	Col. 22	Col. 16	Col. 27
	Press	C	Col. 4	Col. 5	Col. 11	Col. 22	Col. 16	Col. 28
Minor diameter	Sliding	X	Col. 4	Col. 12*	Col. 11	Col. 22	Col. 16	Col. 26
	Location	Y	Col. 4	Col. 13*	Col. 11	Col. 22	Col. 16*	Col. 26
	Press	Z	Col. 4	Col. 14*	Col. 11	Col. 22	Col. 16*	Col. 26

* Requires special tooling.
See Table 54*d* for tolerances and formulas.

Ball Bearing Installations.—Because of the wide use of ball bearings on spline shafts, it will often be convenient to know the nearest size of spline for any given ball bearing bore. Table 56 is for such selection, and the major diameters given are for that nearest under the metric bore dimension. Those values underlined are only a few thousandths over the metric size, but considered within the major diameter tolerance. These may be used if desired by making the spline major diameter as recommended by the ball bearing manufacturer, provided it does not interfere with a major diameter fit.

Tooth Side-fit Tolerance.—The Class A fit is based on circular clearance or blacklash of

0.0020 to 0.0060 for D.P. from $\frac{1}{2}$ to $\frac{4}{8}$ inclusive
0.0015 to 0.0045 for D.P. from $\frac{5}{10}$ to $\frac{8}{16}$ inclusive
0.0010 to 0.0040 fro D.P. from $\frac{10}{20}$ to $\frac{20}{40}$ inclusive
0.0010 to 0.0030 for D.P. from $\frac{24}{48}$ to $\frac{48}{96}$ inclusive

The tolerances for space width and tooth circular thickness are divided as follows:

D.P.	Internal Tolerance		External Tolerance	
$\frac{1}{2}$ to $\frac{4}{8}$	+.0020	−.0000	+.0000	−.0020
$\frac{5}{10}$ to $\frac{8}{16}$	+.0015	−.0000	+.0000	−.0015
$\frac{10}{20}$ to $\frac{20}{40}$	+.0010	−.0000	+.0000	−.0015
$\frac{24}{48}$ to $\frac{48}{96}$	+.0010	−.0000	+.0000	−.0010

These tolerances multiplied by the cotangent of ϕ_1, give the tolerances used at the top of columns 11 and 26, Tables 54*d* and 54*e*.

TABLE 54.—COMPARATIVE DIMENSIONS

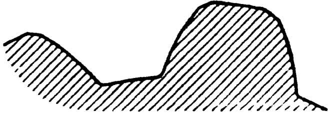
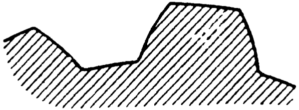
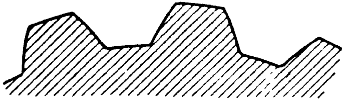
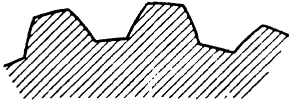
Actual Size	Diam. Pitch	Addendum Dedendum	Circ. Pitch	Circ. Space	Pin Diameter	
					Exter.	Inter.
	2.5/5	0.2000	1.2566	0.6283	0.7680	0.5760
	3/6	0.1667	1.0472	0.5236	0.6400	0.4800
	4/8	0.1250	0.7854	0.3027	0.4800	0.3600
	5/10	0.1000	0.6283	0.3142	0.3840	0.2880

TABLE 54*a*.—COMPARATIVE DIMENSIONS—(*Continued*)

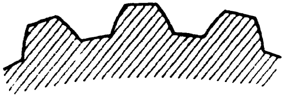
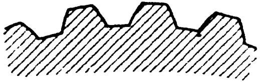
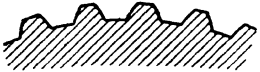
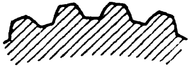
Actual Size	Diam. Pitch	Addendum Dedendum	Circ. Pitch	Circ. Space	Pin Diameter	
					Exter.	Inter.
	6/12	0.0833	0.5236	0.2618	0.3200	0.2400
	8/16	0.0625	0.3927	0.1963	0.2400	0.1800
	10/20	0.0500	0.3142	0.1571	0.1920	0.1440
	12/24	0.0417	0.2618	0.1309	0.1600	0.1200

TABLE 54*b*.—SPLINE SELECTION FOR BALL BEARINGS

Bearing Bore		Nearest Number of Teeth and Major Diameter under Bearing Bore													
Mm.	In.	2.5/5	3/6	4/8	5/10	6/12	8/16	10/20	12/24	16/32	20/40	24/48	32/64	40/80	48/96
10	0.3937										6-0.350	8-0.375	11-0.375	14-0.375	18-0.395
12	0.4724									6-0.438	8-0.450	10-0.548	14-0.460	18-0.475	21-0.458
15	0.5906								6-0.583	8-0.562	10-0.550	13-0.583	18-0.594	22-0.575	27-0.583
17	0.6693								7-0.667	9-0.625	13-0.700	15-0.667	20-0.656	25-0.650	31-0.667
20	0.7874							6-0.709	8-0.750	11-0.750	14-0.750	18-0.792	24-0.781	30-0.775	37-0.792
25	0.9843						6- 0.875	8-0.900	10-0.917	14-0.938	18-0.950	22-0.958	30-0.969	38-0.975	46-0.979
30	1.1811					6- 1.167	8- 1.125	10-1.100	13-1.167	17-1.125	22-1.150	27-1.167	36-1.156	46-1.175	55-1.167
35	1.3780					7- 1.333	10- 1.375	12-1.300	15-1.333	21-1.375	26-1.350	32-1.375	43-1.375	54-1.375	65-1.375
40	1.5748				6- 1.400	8- 1.500	11- 1.500	14-1.500	17-1.500	24-1.563	30-1.550	36-1.542	49-1.563	62-1.575	74-1.563
45	1.7717			6- 1.750	7- 1.600	9- 1.667	13- 1.750	16-1.700	20-1.750	27-1.750	34-1.750	41-1.750	55-1.750	70-1.775	84-1.771
50	1.9685			6- 1.750	8- 1.800	10- 1.833	14- 1.875	18-1.000	22-1.917	30-1.938	38-1.950	46-1.958	62-1.937	77-1.950	93-1.958
55	2.1654			7- 2.000	9- 2.000	12- 2.167	16- 2.125	20-2.100	24-2.083	33-2.125	42-2.150	51-2.167	68-2.156	85-2.150	
60	2.3622		6- 2.333	8- 2.250	10- 2.200	13- 2.333	17- 2.250	22-2.300	27-2.333	36-2.313	46-2.350	55-2.333	74-2.343	93-2.350	
65	2.5591		6- 2.333	9- 2.500	11- 2.400	14- 2.500	19- 2.500	24-2.500	29-2.500	39-2.500	50-2.550	60-2.542	81-2.562		
70	2.7559		7- 2.667	10- 2.750	12- 2.600	15- 2.667	21- 2.750	26-2.700	32-2.750	43-2.750	54-2.750	65-2.750	87-2.750		
75	2.9528	6- 2.800	7- 2.667	10- 2.750	13- 2.800	16- 2.833	22- 2.875	28-2.900	34-2.917	46-2.938	58-2.950	60-2.917	93-2.938		
80	3.1496	6- 2.800	8- 3.000	11- 3.000	14- 3.000	17- 3.000	24- 3.125	30-3.100	36-3.083	49-3.125	62-3.150	74-3.125	99-3.125		
85	3.3465	7- 3.200	9- 3.333	12- 3.250	15- 3.200	19- 3.333	25- 3.250	32-3.300	39-3.333	52-3.312	66-3.350	79-3.333			
90	3.5433	7- 3.200	9- 3.333	13- 3.500	16- 3.400	20- 3.500	27- 3.500	34-3.500	41-3.500	55-3.500	69-3.500	83-3.542			
95	3.7402	8- 3.600	10- 3.667	14- 3.750	17- 3.600	21- 3.667	28- 3.625	36-3.700	43-3.667	58-3.688	73-3.700	88-3.708			

TABLE 54*b*.—SPLINE SELECTION FOR BALL BEARINGS.—*Continued*

Bearing Bore		Nearest Number of Teeth and Major Diameter under Bearing Bore													
Mm.	In.	2.5/5	3/6	4/8	5/10	6/12	8/16	10/20	12/24	16/32	20/40	24/48	32/64	40/80	48/96
100	3.9370	8– 3.600	10– 3.667	14– 3.750	18– 3.800	22– 3.833	30– 3.875	38–3.900	46–3.917	62–3.938	77–3.900	93–3.917			
105	4.1339	9– 4.000	11– 4.000	15– 4.000	19– 4.000	23– 4.000	32– 4.125	40–4.100	48–4.083	65–4.125	81–4.100	98–4.125			
110	4.3307	9– 4.000	12– 4.333	16– 4.250	20– 4.200	25– 4.333	33– 4.250	42–4.300	50–4.250	68–4.312	85–4.300				
120	4.7244	10– 4.400	13– 4.667	17– 4.500	22– 4.600	27– 4.667	36– 4.625	46–4.700	55–4.667	74–4.688	93–4.700				
130	5.1181	11– 4.800	14– 5.000	19– 5.000	24– 5.000	29– 5.000	39– 5.000	50–5.100	60–5.083	80–5.062					
140	5.5118	12– 5.200	15– 5.333	21– 5.500	26– 5.400	32– 5.500	43– 5.500	54–5.500	65–5.500	87–5.500					
150	5.9055	13– 5.600	16– 5.667	22– 5.750	28– 5.800	34– 5.833	46– 5.875	58–5.900	69–5.833	93–5.875					
160	6.2992	14– 6.000	17– 6.000	24– 6.250	30– 6.200	36– 6.167	49– 6.250	62–6.300	74–6.250	99–6.250					
170	6.6929	15– 6.400	19– 6.667	25– 6.500	32– 6.600	39– 6.667	52– 6.625	65–6.600	79–6.667						
180	7.0866	16– 6.800	20– 7.000	27– 7.000	34– 7.000	41– 7.000	55– 7.000	69–7.000	84–7.803						
190	7.4803	17– 7.200	21– 7.333	28– 7.250	36– 7.400	43– 7.333	58– 7.375	73–7.400	88–7.417						
200	7.8740	18– 7.600	22– 7.667	30– 7.750	38– 7.800	46– 7.833	62– 7.875	77–7.800	93–7.833						
210	8.2677	19– 8.000	23– 8.000	32– 8.250	40– 8.200	48– 8.167	65– 8.250	81–8.200	98–8.250						
220	8.6614	20– 8.400	25– 8.667	33– 8.500	42– 8.600	51– 8.667	68– 8.625	85–8.600							
230	9.0551	21– 8.800	26– 9.000	35– 9.000	44– 9.000	53– 9.000	71– 9.000	89–9.000							
240	9.4488	22– 9.200	27– 9.333	36– 9.250	46– 9.400	55– 9.333	74– 9.375	93–9.400							
250	9.8425	23– 9.600	28– 9.667	38– 9.750	48– 9.800	58– 9.833	77– 9.750	97–9.800							
260	10.2362	24–10.000	29–10.000	40–10.250	50–10.200	60–10.167	80–10.125								
280	11.0236	26–10.800	32–11.000	43–11.000	54–11.000	65–11.000	87–11.000								
320	12.5984	30–12.400	36–12.333	49–12.500	61–12.400	74–12.500	99–12.500								

$$D_o = \frac{N+1}{P}$$

$$N = D_oP - 1$$

Underlined figures indicate a major diameter slightly greater than bearing bore, but within the allowable major diameter tolerance.

TABLE 54c.—BASIC DATA: $\frac{1}{2}$ D.P., EXTERNAL

N (1)	(Basic Cond. Diam.) $D \cos 30°$ (2)	$\frac{t_s^*}{D}$ (3)	$\frac{1.920}{D \cos 30}$ (4)	$\frac{\pi}{N}$ (5)	Inv. ϕ_2 (6)	$\phi_2°$ (7)	$\cos \phi_2$ (8)	$\frac{D \cos 30}{\cos \phi_2}$ (9)	$\frac{90}{N}$ (10)	$\cot \phi_2$ (11)
6	5.1961524	0.261799388	0.369504	0.5235987	0.1614562	41.5761	0.7480750	6.94603	15.00000	1.13
7	6.0621778	0.224399475	0.316718	0.4487989	0.1460701	40.4092	0.7614343	7.96152	12.85714	1.17
8	6.9282032	0.196349541	0.277128	0.3926990	0.1345300	39.4661	0.7719975	8.97439	11.25000	1.21
9	7.7942286	0.174532925	0.246336	0.3490658	0.1255546	38.6862	0.7805810	9.98516	10.00000	1.25
10	8.6602540	0.157079633	0.221702	0.3141592	0.1183744	38.0293	0.7876959	10.99441	9.00000	1.28
11	9.5262794	0.142799666	0.201548	0.2855992	0.1124995	37.4679	0.7936943	12.00244	8.18182	1.31
12	10.3923048	0.130899693	0.184752	0.2617994	0.1076038	36.9818	0.7988266	13.00946	7.50000	1.33
13	11.2583302	0.120830486	0.170540	0.2416609	0.1034164	36.5569	0.8032658	14.01569	6.92308	1.35
14	12.1243556	0.112199737	0.158359	0.2243994	0.0999108	36.1818	0.8071478	15.02123	6.42857	1.37
15	12.9903810	0.104719755	0.147802	0.2094395	0.0968337	35.8483	0.8105704	16.02622	6.00000	1.38
16	13.8564064	0.098174770	0.138564	0.1963495	0.0941408	35.5494	0.8136145	17.03067	5.62500	1.40
17	14.7224318	0.092399783	0.130413	0.1847995	0.0917647	35.2802	0.8163372	18.03474	5.29412	1.41
18	15.5884572	0.087266462	0.123168	0.1745329	0.0896530	35.0362	0.8187895	19.03841	5.00000	1.43
19	16.4544826	0.082673490	0.116685	0.1653469	0.0877631	34.8142	0.8210078	20.04181	4.73684	1.44
20	17.3205080	0.078539816	0.110851	0.1570796	0.0860627	34.6112	0.8230254	21.04492	4.50000	1.45
21	18.1865334	0.074799825	0.105573	0.1495996	0.0845247	34.4249	0.8248679	22.04781	4.28571	1.46
22	19.0525588	0.071399833	0.100774	0.1427996	0.0831257	34.2531	0.8265593	23.05044	4.09091	1.47
23	19.9185842	0.068295492	0.096392	0.1365910	0.0818480	34.0943	0.8281161	24.05288	3.91304	1.48
24	20.7846096	0.065449846	0.092376	0.1308997	0.0806776	33.9471	0.8295535	25.05517	3.75000	1.49
25	21.6506350	0.062831853	0.088681	0.1256637	0.0796006	33.8103	0.8308845	26.05733	3.60000	1.49
26	22.5166604	0.060415243	0.085270	0.1208305	0.0786062	33.6826	0.8321226	27.05930	3.46154	1.50
27	23.3826858	0.058177641	0.082112	0.1163553	0.0776858	33.5634	0.8332746	28.06120	3.33333	1.50
28	24.2487112	0.056099868	0.079179	0.1121997	0.0768306	33.4516	0.8343518	29.06293	3.21429	1.51
29	25.1147366	0.054165390	0.076449	0.1083308	0.0760351	33.3467	0.8353596	30.06458	3.10345	1.52
30	25.9807620	0.052359877	0.073901	0.1047197	0.0752927	33.2481	0.8363043	31.06615	3.00000	1.53

TABLE 54c.—BASIC DATA: ½ D.P., EXTERNAL.—*Continued*

N (1)	(Basic Cond. Diam.) $D \cos 30°$ (2)	$\frac{t_s}{D}$* (3)	$\frac{1.920}{D \cos 30}$ (4)	$\frac{\pi}{N}$ (5)	Inv. ϕ_2 (6)	$\phi_2°$ (7)	$\cos \phi_2$ (8)	$\frac{D \cos 30}{\cos \phi_2}$ (9)	$\frac{90}{N}$ (10)	$\cot \phi_2$ (11)
31	26.8467874	0.050670849	0.071517	0.1013417	0.0745976	33.1551	0.8371932	32.06761	2.90323	1.53
32	27.7128128	0.049087385	0.069282	0.0981748	0.0739461	33.0674	0.8380293	33.06902	2.81250	1.54
33	28.5788382	0.047599888	0.067183	0.0951998	0.0733345	32.9844	0.8388188	34.07033	2.72727	1.54
34	29.4448636	0.046199891	0.065207	0.0923998	0.0727586	32.9059	0.8395639	35.07161	2.64706	1.54
35	30.3108890	0.044879895	0.063344	0.0897598	0.0722156	32.8314	0.8402696	36.07281	2.57143	1.55
36	31.1769144	0.043633231	0.061584	0.0872665	0.0717022	32.7605	0.8409399	37.07389	2.50000	1.55
37	32.0429398	0.042453954	0.059920	0.0849079	0.0712175	32.6933	0.8415739	38.07501	2.43243	1.56
38	32.9089652	0.041336745	0.058343	0.0826735	0.0707577	32.6292	0.8421777	39.07603	2.36842	1.56
39	33.7749906	0.040276828	0.056847	0.0805536	0.0703217	32.5681	0.8427522	40.07701	2.30769	1.57
40	34.6410160	0.039269908	0.055426	0.0785398	0.0699076	32.5098	0.8432995	41.07795	2.25000	1.57
41	35.5070414	0.038312105	0.054074	0.0766242	0.0695134	32.4541	0.8438216	42.07884	2.19512	1.57
42	36.3730668	0.037399912	0.052786	0.0747998	0.0691376	32.4007	0.8443214	43.07964	2.14286	1.58
43	37.2390922	0.036530147	0.051559	0.0730602	0.0687804	32.3498	0.8447971	44.08051	2.09302	1.58
44	38.1051176	0.035699916	0.050387	0.0713998	0.0684386	32.3009	0.8452534	45.08129	2.04546	1.58
45	38.9711430	0.034906585	0.049267	0.0698131	0.0681120	32.2540	0.8456906	46.08203	2.00000	1.58
46	39.8371684	0.034147746	0.048196	0.0682954	0.0677998	32.2090	0.8461095	47.08275	1.95652	1.59
47	40.7031938	0.033421198	0.047171	0.0668423	0.0675014	32.1658	0.8465111	48.08347	1.91489	1.59
48	41.5692192	0.032724923	0.046188	0.0654498	0.0672146	32.1242	0.8468974	49.08412	1.87500	1.59
49	42.4352446	0.032057067	0.045245	0.0641141	0.0669395	32.0842	0.8472684	50.08477	1.83674	1.60
50	43.3012700	0.031415926	0.044341	0.0628318	0.0666766	32.0458	0.8476242	51.08545	1.80000	1.60

CONSTANTS

$\pi = 3.141592654$

$\cos 30° = 0.8660254$

Inv. $30° = 0.05375149$

For basic condition of $t = \frac{\text{circ. pitch}}{2}$, $D = N$; and therefore, inv. $\phi_2 = \frac{0.646228716}{N} + 0.05375149$

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* Basically $t_s = t =$ circular pitch/2 and while t_s is used for internal, t is varied as desired.

TABLE 54*d*.—INVOLUTE SPLINES
All dimensions in inches

1/2 Diametral Pitch Pressure angle 30°							Circular pitch Cir. tooth thickness						3.1416 1.5708
Inter. & Exter.				Internal									
N	Pitch Diam.	Base Circle Diam.	Major Diam. Basic	Minor Diam.	T.I.F. Diam.	Major Diam. Fillet		Minor Diam.‡ Chamfer		Meas. betw'n Pins*	Minor Diameter Fit Minor Diam.		
	Ref.	Ref.		Min.	Min.	Rad.	Ht.	Ang.	Ht.	Basic	Class X	Class Y	Class Z
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Recommended tolerance			+0.0015 −0.0030†	+0.0050 −0.0000	Min.	Approx.	Max.	*D°–M′*	Min.	+0.0037 −0.0000	+0.0040 −0.0000	+0.0015 −0.0015	+0.0015 −0.0015
6	6.000	5.19615	7.000	5.337	6.915			53–37	0.2020	4.3933	5.002	5.0012	4.9930
7	7.000	6.06218	8.000	6.300	7.914			53–34	0.1801	5.2231	6.002	6.0013	5.9925
8	8.000	6.92820	9.000	7.274	8.910	0.1699	0.0659	53–31	0.1641	6.3954	7.002	7.0014	6.9920
9	9.000	7.79423	10.000	8.254	9.907	0.1777	0.0709	53–29	0.1521	7.2618	8.002	8.0015	7.9915
10	10.000	8.66025	11.000	9.238	10.906	0.1838	0.0751	53–29	0.1425	8.3966	9.002	9.0016	8.9910
11	11.000	9.52628	12.000	10.225	11.906	0.1887	0.0785	53–28	0.1350	9.2826	10.002	10.0017	9.9905
12	12.000	10.39230	13.000	11.215	12.905	0.1926	0.0814	53–29	0.1289	10.3973	11.002	11.0018	10.9900
13	13.000	11.25833	14.000	12.206	13.905	0.1950	0.0840	53–29	0.1235	11.3040	12.002	12.0019	11.9895
14	14.000	12.12436	15.000	13.198	14.904	0.1987	0.0861	53–30	0.1190	12.3978	13.002	13.0020	12.9890
15	15.000	12.99038	16.000	14.192	15.904	0.2011	0.0880	53–31	0.1152	13.3167	14.002	14.0021	13.9885
16	16.000	13.85641	17.000	15.186	16.901	0.2032	0.0897	53–31	0.1118	14.3982	15.002	15.0022	14.9880
17	17.000	14.72243	18.000	16.182	17.901	0.2050	0.0912	53–32	0.1090	15.3266	16.002	16.0023	15.9875
18	18.000	15.58846	19.000	17.177	18.900	0.2066	0.0925	53–32	0.1063	16.3985	17.002	17.0024	16.9870
19	19.000	16.45448	20.000	18.173	19.900	0.2080	0.0937	53–33	0.1040	17.3345	18.002	18.0025	17.9865
20	20.000	17.32051	21.000	19.170	20.900	0.2093	0.0948	53–34	0.1020	18.3987	19.002	19.0026	18.9860

21	21.000	18.18653	22.000	20.167	21.900	0.2104	0.0957	53–35	0.1002	19.3410	20.002	20.0027	19.9855
22	22.000	19.05256	23.000	21.164	22.900	0.2115	0.0966	53–36	0.0984	20.3989	21.002	21.0028	20.9850
23	23.000	19.91868	24.000	22.162	23.900	0.2124	0.0974	53–37	0.0968	21.3467	22.002	22.0029	21.9845
24	24.000	20.78461	25.000	23.160	24.900	0.2133	0.0982	53–38	0.0955	22.3991	23.002	23.0030	22.9840
25	25.000	21.65063	26.000	24.157	25.900	0.2141	0.0989	53–38	0.0943	23.3513	24.002	24.0031	23.9835
26	26.000	22.51666	27.000	25.155	26.900	0.2148	0.0995	53–39	0.0930	24.3992	25.002	25.0032	24.9830
27	27.000	23.38268	28.000	26.153	27.900	0.2154	0.1001	53–40	0.0919	25.3551	26.002	26.0033	25.9825
28	28.000	24.24871	29.000	27.152	28.900	0.2160	0.1007	53–40	0.0910	26.3993	27.002	27.0034	26.9820
29	29.000	25.11474	30.000	28.150	29.900	0.2166	0.1012	53–41	0.0900	27.3582	28.002	28.0035	27.9815
30	30.000	25.98076	31.000	29.149	30.900	0.2172	0.1016	53–41	0.0892	28.3994	29.002	29.0036	28.9810
31	31.000	26.84678	32.000	30.147	31.900	0.2177	0.1021	53–41	0.0883	29.3607	30.002	30.0037	29.9805
32	32.000	27.71281	33.000	31.146	32.900	0.2181	0.1025	53–42	0.0875	30.3995	31.002	31.0038	30.9800
33	33.000	28.57884	34.000	32.145	33.900	0.2185	0.1029	53–43	0.0868	31.3628	32.002	32.0039	31.9795
34	34.000	29.44486	35.000	33.144	34.900	0.2189	0.1033	53–43	0.0862	32.3995	33.002	33.0040	32.9790
35	35.000	30.31089	36.000	34.143	35.900	0.2193	0.1037	53–44	0.0856	33.3645	34.002	34.0041	33.9785
36	36.000	31.17691	37.000	35.142	36.900	0.2197	0.1040	53–44	0.0850	34.3996	35.002	35.0042	34.9780
37	37.000	32.04294	38.000	36.141	37.900	0.2201	0.1043	53–44	0.0845	35.3661	36.002	36.0043	35.9775
38	38.000	32.90896	39.000	37.140	38.900	0.2204	0.1046	53–45	0.0840	36.3996	37.002	37.0044	36.9770
39	39.000	33.77499	40.000	38.139	39.900	0.2207	0.1049	53–46	0.0838	37.3677	38.002	38.0045	37.9765
40	40.00	34.64102	41.000	39.138	40.900	0.2210	0.1052	53–46	0.0830	38.3997	39.002	39.0046	38.9760
41	41.000	35.50704	42.000	40.137	41.900	0.2213	0.1055	53–46	0.0825	39.3692	40.002	40.0047	39.9755
42	42.000	36.37307	43.000	41.137	42.900	0.2215	0.1057	53–47	0.0820	40.5997	41.002	41.0048	40.9750
43	43.000	37.23909	44.000	42.136	43.900	0.2217	0.1059	53–47	0.0815	41.3706	42.002	42.0049	41.9745
44	44.000	38.10512	45.000	43.135	44.900	0.2220	0.1061	53–47	0.0811	42.3998	43.002	43.0050	42.9740
45	45.000	38.97114	46.000	44.135	45.900	0.2222	0.1063	53–48	0.0808	43.3719	44.002	44.0051	43.9735
46	46.000	39.83716	47.000	45.134	46.900	0.2224	0.1065	53–49	0.0804	44.3998	45.002	45.0052	44.9730
47	47.000	40.70319	48.000	46.134	47.900	0.2226	0.1067	53–49	0.0800	45.3732	46.002	46.0053	45.9725
48	48.000	41.56922	49.000	47.133	48.900	0.2228	0.1069	53–49	0.0797	46.3999	47.002	47.0054	46.9720
49	49.000	42.43524	50.000	48.133	49.900	0.2230	0.1071	53–50	0.0794	47.3745	48.002	48.0055	47.9715
50	50.000	43.30127	51.000	49.132	50.900	0.2232	0.1073	53–50	0.0791	48.3999	49.002	49.0056	48.9710

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* Pins flattened. See Fig. 25.

† Applies to internal only.

‡ Use only with class X, Y, and Z fits.

ϕ = pressure angle at PD (30°)
ϕ_2 = pressure angle at pin center
d_x = pin diameter

$$\text{Inv. } \phi_2 = \frac{t}{D} + \text{inv. } 30^\circ + \frac{d_x}{D \cos 30^\circ} - \frac{\pi}{N} \tag{1}$$

From inv. ϕ_2 find ϕ_2 in degrees if N is even

$$C_1 = \frac{D \cos 30^\circ}{\cos \phi_2} + d_x \tag{1.1}$$

If N is odd

$$C_2 = \frac{D \cos 30^\circ \cos \dfrac{90^\circ}{N}}{\cos \phi_2} + d_x \tag{1.2}$$

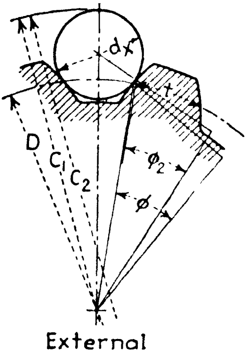


FIG. 24.

Example—for 10/20 DP—20 teeth—0.001 clear,

$$\text{Inv. } \phi_2 = \frac{0.1561}{2.000} + 0.05375149 + \frac{0.1920}{2.000 \times 0.86602} - \frac{\pi}{20}$$

$$\text{Inv. } \phi_2 = 0.08557314 \qquad \phi_2 = 34.552149^\circ$$

Use (1.1) because N is even

$$C_1 = \frac{2.000 \times 0.86602}{\cos 34.552149} + 0.1920 = 2.2950$$

Due to interference with major diameter, pin must be flattened as shown.

$$\text{Inv. } \phi_s = \text{inv. } 30^\circ + \frac{t_s}{D} - \frac{d_n}{D \cos 30^\circ} \tag{1.3}$$

If N is even

$$G_1 = \frac{D \cos 30^\circ}{\cos \phi_3} - d_n \tag{1.4}$$

If N is odd

$$G_2 = \frac{D \cos 30^\circ \cos \dfrac{90^\circ}{N}}{\cos \phi_3} - d_n \tag{1.5}$$

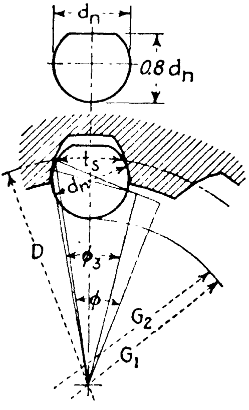


FIG. 25.

Example—for 10/20 *DP*—20 teeth

$$\text{Inv. } \phi_3 = 0.05375149 + \frac{0.1571}{2.000} - \frac{0.1440}{2.000 \times 0.86602}$$

$$\text{Inv. } \phi_3 = 0.04916305 \qquad \phi_3 = 29.18496^\circ$$

Use (1.4) because N is even

$$G_1 = \frac{2.000 \times 0.86602}{\cos 29.18496} - 0.1440 = 1.8399.$$

TABLE 54e.—INVOLUTE SPLINES
All Dimensions in Inches

Addendum	0.5000	Measuring pin diam., external	1.920
Dedendum	0.5000	Measuring pin diam., internal	1.440

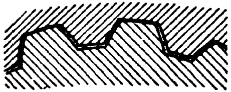
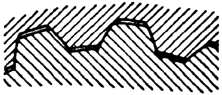
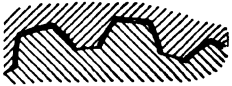
External

N	Minor Diam., Basic +0.0000 −0.0030*	T.I.F. Diam. Max.	Minor Diam. Fillet		Major Diam. Chamfer		Major Diam. Fit			Meas. over Pins, Basic	Tooth Side Fit		
							Major Diam.				Meas. over Pins		
			Rad. App.	HT. Max.	Dim. App.	HT. Min.	Class I +0.0000 −0.0040	Class II +0.0000 −0.0025	Class III +0.0000 −0.0030		Class A +0.0000 −0.0027	Class B +0.0000 −0.0027	Class C +0.0000 −0.0027
(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)
6	5.000	5.337	0.170	0.1683	0.228	0.0911	6.995	6.9992	7.0080	8.8660	8.8637	8.8679	8.8742
7	6.000	6.300	0.150	0.1501	0.230	0.0935	7.995	7.9991	8.0085	9.6819	9.6796	9.6838	9.6904
8	7.000	7.274	0.140	0.1369	0.230	0.0953	8.995	8.9990	9.0090	10.8944	10.8920	10.8963	10.9032
9	8.000	8.254	0.130	0.1268	0.232	0.0967	9.995	9.9989	10.0095	11.7535	11.7510	11.7554	11.7626
10	9.000	9.238	0.120	0.1189	0.233	0.0978	10.995	10.9988	11.0100	12.9144	12.9118	12.9163	12.9238
11	10.000	10.225	0.116	0.1126	0.234	0.0988	11.995	11.9987	12.0105	13.8003	13.7977	13.8022	13.8100
12	11.000	11.215	0.110	0.1073	0.234	0.0997	12.995	12.9986	13.0110	14.9295	14.9268	14.9314	14.9395
13	12.000	12.206	0.108	0.1029	0.235	0.1004	13.995	13.9985	14.0115	15.8335	15.8308	15.8354	15.8438
14	13.000	13.198	0.105	0.0992	0.235	0.1011	14.995	14.9984	15.0120	16.9412	16.9385	16.9431	16.9518
15	14.000	14.192	0.102	0.0960	0.236	0.1016	15.995	15.9983	16.0125	17.8584	17.8556	17.8603	17.8693
16	15.000	15.186	0.100	0.0932	0.236	0.1021	16.995	16.9982	17.0130	18.9507	18.9497	18.9526	18.9619
17	16.000	16.182	0.100	0.0908	0.236	0.1026	17.995	17.9981	18.0135	19.8778	19.8750	19.8797	19.8893
18	17.000	17.177	0.100	0.0886	0.237	0.1030	18.995	18.9980	19.0140	20.9584	20.9555	20.9603	20.9702
19	18.000	18.173	0.100	0.0867	0.237	0.1033	19.995	19.9979	20.0145	21.8934	21.8905	21.8953	21.9055
20	19.000	19.170	0.100	0.0850	0.237	0.1030	20.995	20.9978	21.0150	22.9649	22.9620	22.9668	22.9773

21	20.000	20.167	0.100	0.0834	0.237	0.1039	21.995	21.9977	22.0155	23.9061	23.9032	23.9080	23.9188
22	21.000	21.164	0.100	0.0820	0.237	0.1042	22.995	22.9976	23.0160	24.9704	24.9675	24.9722	24.9834
23	22.000	22.161	0.100	0.0807	0.238	0.1044	23.995	23.9975	24.0165	25.9168	25.9138	25.9187	25.9301
24	23.000	23.159	0.100	0.0796	0.238	0.1046	24.995	24.9974	25.0170	26.9752	26.9732	26.9771	26.9888
25	24.000	24.159	0.100	0.0785	0.238	0.1048	25.995	25.9973	26.0175	27.9259	27.9229	27.9278	27.9398
26	25.000	25.155	0.100	0.0775	0.238	0.1050	26.995	26.9972	27.0180	28.9793	28.9763	28.9812	28.9935
27	26.000	26.153	0.100	0.0766	0.239	0.1052	27.995	27.9971	28.0185	29.9337	29.9307	29.9356	29.9482
28	27.000	27.152	0.100	0.0758	0.239	0.1054	28.995	28.9970	29.0190	30.9829	30.9799	30.9848	30.9077
29	28.000	28.150	0.100	0.0750	0.239	0.1056	29.995	29.9969	30.0195	31.9405	31.9375	31.9424	31.9556
30	29.000	29.149	0.100	0.0743	0.239	0.1057	30.995	30.9968	31.0200	32.9862	32.9832	32.9881	33.0018
31	30.000	30.147	0.100	0.0736	0.239	0.1059	31.995	31.9967	32.0205	33.9465	33.9434	33.9484	33.9622
32	31.000	31.146	0.100	0.0729	0.239	0.1060	32.995	32.9966	33.0210	34.9890	34.9859	34.9909	35.0050
33	32.000	32.145	0.100	0.0723	0.239	0.1061	33.995	33.9965	34.0215	35.9517	35.9486	35.9536	35.9680
34	33.000	33.144	0.100	0.0718	0.239	0.1062	34.995	34.9964	35.0220	36.9916	36.9885	36.9935	37.0082
35	34.000	34.143	0.100	0.0713	0.239	0.1063	35.995	35.9963	36.0225	37.9564	37.9533	37.9583	37.9733
36	35.000	35.142	0.100	0.0708	0.240	0.1064	36.995	36.9962	37.0230	38.9939	38.9908	38.9958	39.0111
37	36.000	36.140	0.100	0.0703	0.240	0.1065	37.995	37.9961	38.0235	39.9606	39.9575	39.9625	39.9781
38	37.000	37.140	0.100	0.0698	0.240	0.1066	38.995	38.9960	39.0240	40.9960	40.9929	04.9979	41.0138
39	38.000	38.139	0.100	0.0694	0.240	0.1067	39.995	39.9959	40.0245	41.9645	41.9615	41.9664	41.9826
40	39.000	39.138	0.100	0.0690	0.240	0.1068	40.995	40.9958	41.0250	42.9980	42.9949	42.9999	43.0164
41	40.000	40.137	0.100	0.0686	0.240	0.1069	41.995	41.9957	42.0255	43.9679	43.9648	43.9698	43.9866
42	41.000	41.137	0.100	0.0683	0.240	0.1070	42.995	42.9956	43.0260	44.9996	44.9964	45.0015	45.0186
43	42.000	42.136	0.100	0.0679	0.240	0.1070	43.995	43.9955	44.0265	45.9710	45.9678	45.9729	45.9903
44	43.000	43.135	0.100	0.0676	0.240	0.1071	44.995	44.9954	45.0270	47.0013	46.9981	47.0032	47.0208
45	44.000	44.135	0.100	0.0673	0.240	0.1071	45.995	45.9953	46.0275	47.9740	47.9708	47.9759	47.9939
46	45.000	45.134	0.100	0.0670	0.240	0.1072	46.995	46.9952	47.0280	49.0028	48.9996	49.0047	49.0230
47	46.000	46.133	0.100	0.0667	0.240	0.1072	47.995	47.9951	48.0285	49.9766	49.9734	49.9785	49.9971
48	47.000	47.133	0.100	0.0664	0.240	0.1073	48.995	48.9950	49.0290	51.0041	50.0009	51.0060	51.0249
49	48.000	48.132	0.100	0.0662	0.240	0.1073	49.995	49.9949	50.0295	51.9790	51.9758	51.9809	52.0001
50	49.000	49.132	0.100	0.0659	0.240	0.1073	50.995	50.9948	51.0300	53.0055	52.0023	53.0074	53.0269

* Tolerance applies to minor diameter fits only and column dimension should be used as maximum for all other fits.

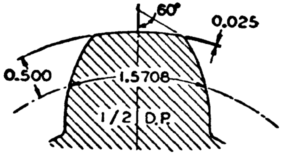
TABLE 54*f*.—EXAMPLES OF FITS

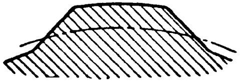
Diametral Pitch	 Major Diameter Fit		 Tooth Side Fit		 Minor Diameter Fit		
	Class I		Class A		Class X		
	Min.	Max.	Min.	Max.	Min.	Max.	
4/8	0.0020 (6 *T*) 0.0020 (50*T*)	0.0105 (6 *T*) 0.0105 (50*T*)	0.0023 (6 *T*) 0.0032 (50*T*)	0.0087 (6 *T*) 0.0096 (50*T*)	0.0020 (6 *T*) 0.0020 (50*T*)	0.0090 (6 *T*) 0.0090 (50*T*)	Sliding
8/16	0.0015 (6 *T*) 0.0015 (50)*T*	0.0075 (6 *T*) 0.0075 (50*T*)	0.0017 (6 *T*) 0.0024 (50*T*)	0.0064 (6 *T*) 0.0071 (50*T*)	0.0015 (6 *T*) 0.0015 (50*T*)	0.0070 (6 *T*) 0.0070 (50*T*)	
16/32	0.0010 (6 *T*) 0.0010 (50*T*)	0.0045 (6 *T*) 0.0045 (50*T*)	0.0017 (6 *T*) 0.0024 (50*T*)	0.0064 (6 *T*) 0.0071 (50*T*)	0.0010 (6 *T*) 0.0010 (50*T*)	0.0050 (6 *T*) 0.0050 (50*T*)	
24/48	0.0010 (6 *T*) 0.0010 (50*T*)	0.0030 (6 *T*) 0.0030 (50*T*)	0.0010 (6 *T*) 0.0016 (50*T*)	0.0042 (6 *T*) 0.0047 (50*T*)	0.0010 (6 *T*) 0.0010 (50*T*)	0.0035 (6 *T*) 0.0035 (50*T*)	
Dimen. →	Col. 4 (min.)	Col. 4 (max.)	Col. 25	Col. 25 + Col. 11 Tol	Col. 12 (min.)	Col. 12 (max.)	
Minus Dimen. →	Col. 22 (max.)	Col. 22 (min.)	Col. 26 (max.)	Col. 26 (min.)	Col. 16 (max.)	Col. 16 (min.)	

	Class II		Class B		Class Y		
	Min.	Max.	Min.	Max.	Min.	Max.	
4/8	−0.0028 (6 *T*) −0.0017 (50*T*)	+0.0042 (6 *T*) +0.0053 (50*T*)	−0.0019 (6 *T*) −0.0019 (50*T*)	+0.0045 (6 *T*) +0.0045 (50*T*)	−0.0012 (6 *T*) −0.0001 (50*T*)	+0.0048 (6 *T*) +0.0059 (50*T*)	Locating
8/16	−0.0019 (6 *T*) −0.0014 (50*T*)	+0.0031 (6 *T*) +0.0036 (50*T*)	−0.0014 (6 *T*) −0.0014 (50*T*)	+0.0033 (6 *T*) +0.0033 (50*T*)	−0.0008 (6 *T*) −0.0003 (50*T*)	+0.0037 (6 *T*) +0.0042 (50*T*)	
16/32	−0.0010 (6 *T*) −0.0007 (50*T*)	+0.0020 (6 *T*) +0.0023 (50*T*)	−0.0014 (6 *T*) −0.0014 (50*T*)	−0.0033 (6 *T*) +0.0033 (50*T*)	−0.0007 (6 *T*) −0.0004 (50*T*)	+0.0029 (6 *T*) +0.0032 (50*T*)	
24/48	−0.0004 (6 *T*) −0.0003 (50*T*)	+0.0016 (6 *T*) +0.0017 (50*T*)	−0.0009 (6 *T*) −0.0009 (50*T*)	+0.0022 (6 *T*) +0.0022 (50*T*)	−0.0004 (6 *T*) −0.0003 (50*T*)	+0.0021 (6 *T*) +0.0022 (50*T*)	
Dimen. → Minus Dimen. →	Col. 23 (max.) Col. 4 (min.)	Col. 4 (max.) Col. 23 (min.)	Col. 27 (max.) Col. 25	Col. 25 + Col. 11 Tol Col. 27 (min.)	Col. 16 (max.) Col. 13 (min.)	Col. 13 (max.) Col. 16 (min.)	
	Class III		Class C		Class Z		
	Min.	Max.	Min.	Max.	Min.	Max.	
4/8	0.0009 (6 *T*) 0.0063 (50*T*)	0.0084 (6 *T*) 0.0138 (50*T*)	0.0005 (6 *T*) 0.0038 (50*T*)	0.0069 (6 *T*) 0.0102 (50*T*)	0.0006 (6 *T*) 0.0061 (50*T*)	0.0066 (6 *T*) 0.0121 (50*T*)	Press
8/16	0.0004 (6 *T*) 0.0032 (50*T*)	0.0059 (6 *T*) 0.0087 (50*T*)	0.0002 (6 *T*) 0.0019 (50*T*)	0.0049 (6 *T*) 0.0066 (50*T*)	0.0003 (6 *T*) 0.0031 (50*T*)	0.0048 (6 *T*) 0.0076 (50*T*)	
16/32	0.0002 (6 *T*) 0.0016 (50*T*)	0.0032 (6 *T*) 0.0046 (50*T*)	0.0001 (6 *T*) 0.0009 (50*T*)	0.0048 (6 *T*) 0.0056 (50*T*)	0.0002 (6 *T*) 0.0015 (50*T*)	0.0038 (6 *T*) 0.0051 (50*T*)	
24/48	0.0001 (6 *T*) 0.0011 (50*T*)	0.0021 (6 *T*) 0.0031 (50*T*)	0.0001 (6 *T*) 0.0006 (50*T*)	0.0032 (6 *T*) 0.0037 (50*T*)	0.0001 (6 *T*) 0.0010 (50*T*)	0.0026 (6 *T*) 0.0035 (50*T*)	
Dimen. → Minus Dimen. →	Col. 24 (min.) Col. 4 (max.)	Col. 24 (max.) Col. 4 (min.)	Col. 28 (min.) Col. 25 + Col. 11 Tol	Col. 28 (max.) Col. 25	Col. 16 (min.) Col. 14 (max.)	Col. 16 (max.) Col. 14 (min.)	

In the first series all figures represent clearance on diameter.
In the second series the minus sign (−) indicates interference or press and the plus sign (+) indicates clearance.
In the third series all figures represent interference or press.

TABLE 548.—SHAPER CUTTERS
Number of Teeth in Cutters Recommended for Internal Splines





Type of Tooth for) Special Champering Cutter

N	Diametral Pitch													
	2.5/5	3/6	4/8	5/10	6/12	8/16	10/20	12/24	16/32	20/40	24/48	32/64	40/80	48/96
6														
7														
8	4	4	4	4	4	4								
9	5	5	5	5	5	5	5							
10	5	5	5	5	5	5	5							
11	6	6	6	6	6	6	6	6						
12	7	7	7	7	7	7	7	7						
13	8	8	8	8	8	8	8	8	8					
14	8	8	8	8	8	8	8	8	8					
15	10	10	10	10	10	10	10	10	10	10				
16	10	10	10	10	10	10	10	10	10	10				
17	10	12	12	12	12	12	12	12	12	12				
18			12	12	12	12	12	12	12	12				
19			12	12	12	12	12	12	12	12				
20			12	15	15	12	15	15	12	15				

21			16	15	15	16	15	15	16	15				
22			16	15	15	16	15	15	16	15				
23			16	15	18	16	15	18	16	15				
24			16	15	18	16	15	18	16	15				
25			20	20	18	20	20	18	20	20				
26					18	20	20	18	20	20				
27					18	20	20	18	20	20				
28					18	20	20	18	20	20				
29					24	24	20	24	24	20				
30						24	25	24	24	25				
31						24	25	24	24	25				
32						24	25	24	24	25				
33						24	25	24	24	25				
34						24	25	24	24	25				
35						24	30	24	24	30				
36						24	30	24	24	30				
37						32	30	24	32	30				
38							30	24		30				
39							30	24		30				
40							30	24		30				
41							30	36		30				
42							30			30				
43							30			30				
44							30			30				
45							40			40				
46							40			40				

Except the 4-tooth cutter, which will cut 8-tooth splines, cutters should be smaller than the part being cut by at least 5 teeth. The largest cutter shown in each pitch may be used to cut all splines having greater numbers of teeth.

HOBS AND BROACHES

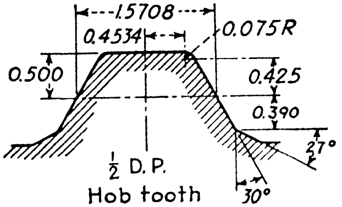
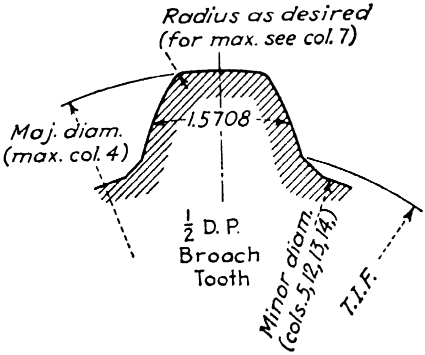


FIG. 26.

RECOMMENDED DIMENSIONS FOR HOBS

D.P.	O.D.	Bore	Width	D.P.	O.D.	Bore	Width
1/2	10.75	2.00	7.50	12/24	2.50	1.25	2.00
2.5/5	5.00	1.50	7.00	16/32	2.50	1.25	2.00
3/6	4.50	1.25	5.00	20/40	2.50	1.25	2.00
4/8	4.00	1.25	4.00	24/48	2.50	1.25	2.00
5/10	3.50	1.25	3.50	32/64	2.50	1.25	2.00
6/12	3.25	1.25	3.25	40/80	2.50	1.25	2.00
8/16	2.50	1.25	2.50	48/96	2.50	1.25	2.00
10/20	2.50	1.25	2.50				

NOTE.—Depth of cut will vary with desired fit. See tables.



Radius as desired (for max. see col. 7)
Maj. diam. (max. col. 4)
.15708
½ D.P.
Broach Tooth
Minor diam. (cols. 5, 12, 13, 14)
T.I.F.

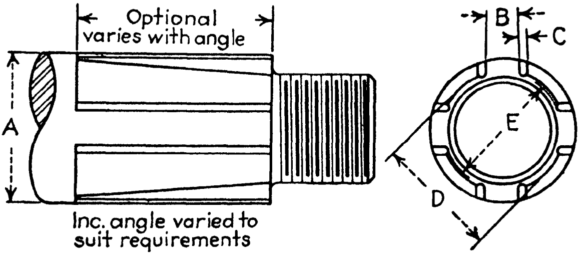
FIG. 27.

Broaches.—The broach design will be in accordance with the specifications given in the tables for internal splines. The length of the broach is determined by the length of the part, the hardness, and type of material to be broached, and the broaching equipment available.

Tapered Splined Shafts

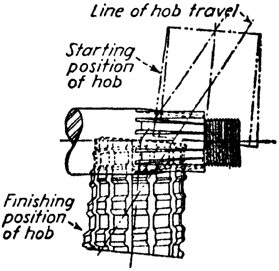
The Barber-Colman Company has developed a tapered spline for shafting and a method of producing it. The shaft itself is not tapered—only the bottom surface of the groove between the splines. The tapered grooves are milled with a tapered hob as shown. The mating part is bored to the same taper as the bottom of the groove and then broached in the usual manner. This permits the passage of the straight outer surface of the splines and gives a bearing on the tapered surfaces. It is self-centering and easily removable.

TABLE 55.—FOUR-KEY SPLINE DIMENSIONS


Optional varies with angle
A
Inc. angle varied to suit requirements
B
C
E
D

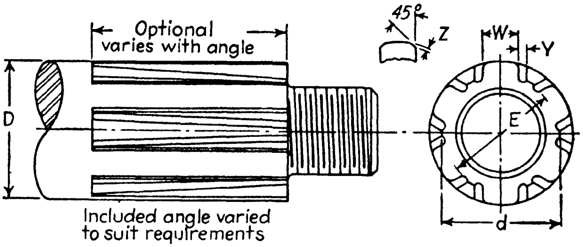
D	*d*	*E*	*W*	*Y* (Approximately)	*Z* (Approximately)	Hob	Broach
1/2"	3/8	11/32	0.120	0.042	0.005	Either	
5/8"	15/32	27/64	0.150	0.051	0.005		
3/4"	9/16	33/64	0.171	0.060	0.005		
7/8"	21/32	19/32	0.211	0.070	0.005		
1"	3/4	11/16	0.241	0.080	0.005		

Barber-Colman Company, Rockford, Ill.



The taper hob moves at the angle shown and cuts the splines deeper as its larger diameter contacts the work.

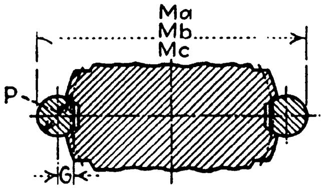
TABLE 56.—SIX-KEY SPLINE DIMENSIONS
(In Inches)


Optional varies with angle
D
Included angle varied to suit requirements
45°
Z
W
Y
E
d

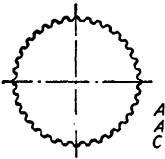
D	*d*	*E*	*W*	*Y* (Approximately)	*Z* (Approximately)	Hob	Broach
1″	0.800	$\frac{3}{4}$	$\frac{1}{4}$	0.059	0.005	Either	
$1\frac{1}{8}''$	0.900	$\frac{27}{32}$	$\frac{9}{32}$	0.066	0.005		
$1\frac{1}{4}''$	1.000	$\frac{15}{16}$	$\frac{5}{16}$	0.077	0.005		
$1\frac{3}{8}''$	1.100	$1\frac{1}{32}$	$\frac{11}{32}$	0.084	0.005		
$1\frac{1}{2}''$	1.200	$1\frac{1}{8}$	$\frac{3}{8}$	0.091	0.005		
$1\frac{5}{8}''$	1.300	$1\frac{7}{32}$	$\frac{13}{32}$	0.098	0.005		
$1\frac{3}{4}''$	1.400	$1\frac{5}{16}$	$\frac{7}{16}$	0.104	0.005		
$1\frac{7}{8}''$	1.500	$1\frac{13}{32}$	$\frac{15}{32}$	0.111	0.005		
2″	1.600	$1\frac{1}{2}$	$\frac{1}{2}$	0.118	0.010		
$2\frac{1}{4}''$	1.800	$1\frac{11}{16}$	$\frac{9}{16}$	0.127	0.010		
$2\frac{1}{2}''$	2.000	$1\frac{7}{8}$	$\frac{5}{8}$	0.140	0.010		
$2\frac{3}{4}''$	2.200	$2\frac{1}{16}$	$\frac{11}{16}$	0.154	0.010		
3″	2.400	$2\frac{1}{4}$	$\frac{3}{4}$	0.163	0.015		
$3\frac{1}{4}''$	2.600	$2\frac{7}{16}$	$\frac{13}{16}$	0.176	0.015		
$3\frac{1}{2}''$	2.800	$2\frac{5}{8}$	$\frac{7}{8}$	0.190	0.015		
4″	3.200	3	1	0.216	0.015		

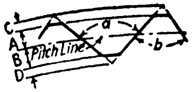
Barber-Colman Company, Rockford, Ill.

TABLE 57.—MEASURING SPLINE DIAMETER WITH PINS
Measurement of Involute Splines (on Shafts)
10-Tooth Splines



Pitch Diameter D_p	Pin Diameter P	Center to Flat G	Measurement over Pins		
			Shallow M_a	Intermediate M_b	Deep M_c
	$D_p \times$ 0.2012936	$0.4P$	$D_p \times$ 1.327628	$D_p \times$ 1.315660	$D_p \times$ 1.3029251
0.7500	0.1510	0.060	0.9957	0.9867	0.9772
0.9375	0.1887	0.075	1.2447	1.2334	1.2215
1.1250	0.2265	0.091	1.4936	1.4801	1.4658
1.3125	0.2642	0.106	1.7425	1.7268	1.7101
1.5000	0.3019	0.121	1.9914	1.9735	1.9544
1.6875	0.3397	0.136	2.2404	2.2202	2.1987
1.8750	0.3774	0.151	2.4893	2.4669	2.4430
2.0625	0.4152	0.166	2.7382	2.7135	2.6873
2.2500	0.4529	0.181	2.9872	2.9602	2.9316
2.4375	0.4907	0.196	3.2361	3.2069	3.1759
2.6250	0.5284	0.211	3.4850	3.4536	3.4202
2.8125	0.5661	0.226	3.7340	3.7003	3.6645
3.0000	0.6039	0.242	3.9829	3.9470	3.9088
3.1875	0.6416	0.257	4.2318	4.1937	4.1531
3.3750	0.6794	0.272	4.4807	4.4404	4.3974
3.5625	0.7171	0.287	4.7297	4.6870	4.6417
3.7500	0.7549	0.302	4.9786	4.9337	4.8860
3.9375	0.7926	0.317	5.2275	5.1804	5.1303
4.1250	0.8303	0.332	5.4765	5.4271	5.3746





A and B are nominally equal
A + B = Depth of cut
C in hole and D in shaft may be made as desired by each individual manufacturer beyond minimum and maximum as specified in table.
N = Number of serrations

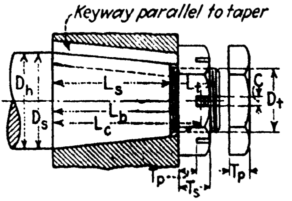
TABLE 58.—SERRATED SHAFT FITTINGS—S.A.E, 1922
Straight Type
(All Dimensions in Inches)

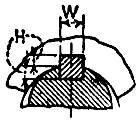
Nominal Diam.	Pitch Diam.		N	a, deg.	b, deg.	Hole			Shaft		
						Large Diam.	Small Diam.		Outside Diam.		Inside Diam.
	Max.	Min.				Min.	Max.	Min.	Max.	Min.	Max.
⅛	0.122	0.120	36	90	80	0.125	0.118	0.117	0.124	0.123	0.116
3/16	0.182	0.180	36	90	80	0.187	0.176	0.175	0.186	0.185	0.174
¼	0.243	0.241	36	90	80	0.250	0.235	0.234	0.249	0.248	0.233
5/16	0.303	0.301	36	90	80	0.312	0.293	0.292	0.311	0.310	0.291
⅜	0.363	0.361	36	90	80	0.375	0.352	0.351	0.374	0.373	0.350
½	0.485	0.483	36	90	80	0.500	0.469	0.468	0.499	0.498	0.467
⅝	0.605	0.603	36	90	80	0.625	0.584	0.583	0.624	0.623	0.582
¾	0.733	0.731	48	90	82½	0.750	0.710	0.714	0.749	0.747	0.713
⅞	0.855	0.853	48	90	82½	0.875	0.835	0.833	0.874	0.872	0.832
1	0.977	0.975	48	90	82½	1.000	0.954	0.952	0.999	0.997	0.951
1⅛	1.098	1.096	48	90	82½	1.125	1.071	1.069	1.124	1.122	1.068
1¼	1.220	1.218	48	90	82½	1.250	1.190	1.188	1.249	1.247	1.187
1⅜	1.342	1.340	48	90	82½	1.375	1.309	1.307	1.374	1.372	1.306
1½	1.464	1.462	48	90	82½	1.500	1.428	1.426	1.499	1.497	1.425
1¾	1.708	1.706	48	90	82½	1.750	1.666	1.664	1.749	1.747	1.663
2	1.952	1.949	48	90	82½	2.000	1.904	1.902	1.999	1.997	1.901
2¼	2.196	2.193	48	90	82½	2.250	2.142	2.140	2.249	2.247	2.139
½	2.440	2.437	48	90	82½	2.500	2.380	2.378	2.499	2.497	2.377
2¾	2.684	2.681	48	90	82½	2.750	2.618	2.616	2.749	2.747	2.615
3	2.928	2.925	48	90	82½	3.000	2.856	2.854	2.999	2.997	2.853

The series of taper serrated shafts commences with the ½-inch nominal outside diameter and continues through the 3-inch diameter. Dimensions for serrations are the same as for corresponding diameters of straight shafts given in table above. For taper shafts all dimensions apply only at the large end of the taper as in the cross-section at the right, where the runout begins. The taper is ¾ inch per foot on the nominal outside diameter *abd*, the cutting angle is 1 degree 37 minutes. (*Tolerance corrected January, 1937.*)

TAPER FITTINGS

PLAIN OR SLOTTED NUTS—S.A.E. STANDARD





Taper per foot = 1.500 ± 0.002 in. Dimension H measured normal to the key.

The center line of the cotter-pin hole shall be 90 degrees from the position of the keyway as shown on the drawing.

TABLE 59.—DIMENSIONS FOR TAPER FITTINGS WITH PLAIN OR SLOTTED NUTS

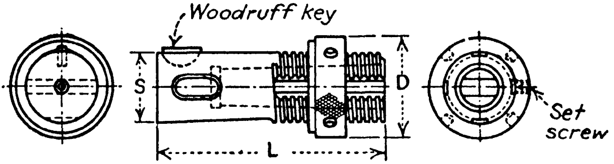
Nom. Diam.	Diam. of Shaft, D_s		Diam. of Hole, D_h		L_c	L_s	L_h	L_t	D_t	Threads per Inch	T_s	T_p	Width of Nut, Flats	W		H		Square Key		C
	Max.	Min.	Max.	Min.										Max.	Min.	Max.	Min.	Max.	Min.	
1/4	0.250	0.249	0.248	0.247	9/16	5/16	3/8	5/16	10	40	7/32	9/64	5/16	0.0625	0.0615	0.0342	0.0327	0.0635	0.0630	5/64
3/8	0.375	0.374	0.373	0.372	47/64	7/16	1/2	23/64	5/16	32	17/64	3/16	1/2	0.0937	0.0927	0.0499	0.0484	0.0947	0.0942	5/64
1/2	0.500	0.499	0.498	0.497	53/64	11/16	3/4	23/64	5/16	32	17/64	3/16	1/2	0.1250	0.1240	0.0655	0.0640	0.1260	0.1255	5/64
5/8	0.625	0.624	0.623	0.622	1 3/32	11/16	3/4	17/32	1/2	28	7/16	1/4	3/4	0.1562	0.1552	0.0811	0.0796	0.1572	0.1567	1/8
3/4	0.750	0.749	0.748	0.747	1 11/32	15/16	1	17/32	1/2	28	7/16	1/4	3/4	0.1875	0.1865	0.0968	0.0953	0.1885	0.1880	1/8
7/8	0.875	0.874	0.873	0.872	1 11/16	1 1/8	1 1/4	11/16	5/8	24	1/2	5/16	15/16	0.2500	0.2490	0.1280	0.1265	0.2510	0.2505	5/32
1	1.001	0.999	0.997	0.995	1 15/16	1 3/8	1 1/2	11/16	3/4	20	1/2	5/16	1 1/16	0.2500	0.2490	0.1280	0.1265	0.2510	0.2505	5/32
1 1/8	1.126	1.124	1.122	1.120	1 15/16	1 3/8	1 1/2	11/16	7/8	20	1/2	5/16	1 1/4	0.3125	0.3115	0.1615	0.1590	0.3140	0.3130	5/32
1 1/4	1.251	1.249	1.247	1.245	1 15/16	1 3/8	1 1/2	11/16	1	20	1/2	5/16	1 7/16	0.3125	0.3115	0.1615	0.1590	0.3140	0.3130	5/32
1 3/8	1.376	1.374	1.372	1.370	2 7/16	1 7/8	2	11/16	1	20	1/2	5/16	1 7/16	0.3750	0.3740	0.1930	0.1905	0.3765	0.3755	5/32
1 1/2	1.501	1.499	1.497	1.495	2 7/16	1 7/8	2	11/16	1	20	1/2	5/16	1 7/16	0.3750	0.3740	0.1930	0.1905	0.3765	0.3755	5/32
1 5/8	1.626	1.624	1.622	1.620	2 13/16	2 1/8	2 1/4	13/16	1 1/4	18	5/8	7/16	2 3/16	0.4375	0.4365	0.2242	0.2217	0.4390	0.4380	5/32
1 3/4	1.751	1.749	1.747	1.745	2 13/16	2 1/8	2 1/4	13/16	1 1/4	18	5/8	7/16	2 3/16	0.4375	0.4365	0.2242	0.2217	0.4390	0.4380	5/32
1 7/8	1.876	1.874	1.872	1.870	3 1/16	2 3/8	2 1/2	13/16	1 1/4	18	5/8	7/16	2 3/16	0.4375	0.4365	0.2242	0.2217	0.4390	0.4380	5/32
2	2.001	1.999	1.997	1.995	3 9/16	2 7/8	3	13/16	1 1/4	18	5/8	7/16	2 3/16	0.5000	0.4990	0.2555	0.2530	0.5015	0.5005	5/32
2 1/4	2.252	2.248	2.245	2.242	3 9/16	2 7/8	3	13/16	1 1/2	18	5/8	7/16	2 3/8	0.5625	0.5610	0.2962	0.2912	0.5645	0.5630	5/32
2 1/2	2.502	2.498	2.495	2.492	4 9/32	3 3/8	3 1/2	1 1/4	2	16	1	5/8	3 1/8	0.6250	0.6235	0.3275	0.3225	0.6270	0.6255	7/32
2 3/4	2.752	2.748	2.745	2.742	4 9/32	3 3/8	3 1/2	1 1/4	2	16	1	5/8	3 1/8	0.6875	0.6860	0.3587	0.3537	0.6895	0.6880	7/32
3	3.002	2.998	2.995	2.992	4 25/32	3 7/8	4	1 1/4	2	16	1	5/8	3 1/8	0.7500	0.7485	0.3900	0.3850	0.7520	0.7505	7/32
3 1/4	3.252	3.248	3.245	3.242	5 1/32	4 1/8	4 1/4	1 1/4	2	16	1	5/8	3 1/8	0.7500	0.7485	0.3900	0.3850	0.7520	0.7505	7/32
3 1/2	3.502	3.498	3.495	3.492	5 7/16	4 3/8	4 1/2	1 3/8	2 1/2	16	1 1/8	3/4	3 7/8	0.8750	0.8735	0.4525	0.4475	0.8770	0.8755	9/32
4	4.002	3.998	3.995	3.992	6 7/16	5 3/8	5 1/2	1 3/8	2 1/2	16	1 1/8	3/4	3 7/8	1.0000	0.9985	0.5150	0.5100	1.0020	1.0005	9/32

Report of Broaches Division adopted by the Society, June, 1914. Last revision by Parts and Fittings Division, February, 1928.

Standard Adapters for Multiple-Spindle Drilling Heads, December, 1937

The purpose of these adapters is to secure vertical adjustment for taper shank tools when used with multiple-spindle drilling heads

TABLE 60.—GENERAL DIMENSIONS OF ASSEMBLY
(In Inches at 68°F.)



Size *S*	A.S.A. Taper Number	Woodruff Key Size	Setscrew Size	Adapter Length *L*	Diameter of Nut *D*
$\frac{3}{4}$	1	$\frac{5}{32} \times \frac{5}{8}$	$\frac{5}{16}$–18 × $\frac{5}{16}$	3	$1\frac{1}{4}$
$1\frac{1}{16}$	1	$\frac{3}{16} \times \frac{7}{8}$	$\frac{5}{16}$–18 × $\frac{5}{16}$	$3\frac{5}{8}$	$1\frac{9}{16}$
$1\frac{1}{16}$	2	$\frac{3}{16} \times \frac{7}{8}$	$\frac{5}{16}$–18 × $\frac{5}{16}$	$3\frac{5}{8}$	$1\frac{9}{16}$
$1\frac{3}{8}$	2	$\frac{1}{4} \times 1$	$\frac{5}{16}$–18 × $\frac{5}{16}$	$4\frac{5}{8}$	$1\frac{7}{8}$
$1\frac{3}{8}$	3	$\frac{1}{4} \times 1$	$\frac{5}{16}$–18 × $\frac{5}{16}$	$4\frac{5}{8}$	$1\frac{7}{8}$
$1\frac{7}{8}$	3	$\frac{5}{16} \times 1\frac{1}{4}$	$\frac{5}{16}$–18 × $\frac{7}{16}$	$5\frac{5}{8}$	$2\frac{5}{8}$
$1\frac{7}{8}$	4	$\frac{5}{16} \times 1\frac{1}{4}$	$\frac{5}{16}$–18 × $\frac{7}{16}$	$5\frac{5}{8}$	$2\frac{5}{8}$

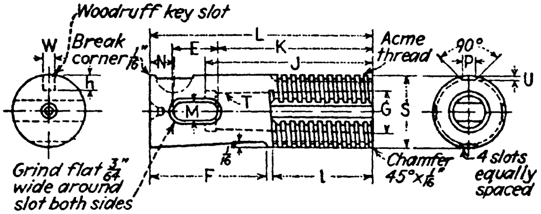
Material.—Chromium-nickel steel, S.A.E. 3120, or equivalent, case hardened.

Finish.—All surfaces must be finished.

Marking.—Thread size and manufacturer's name or trade mark and A.S.A. taper number to be marked on end.

Manufacture.—Tolerances on fractional dimensions are plus or minus 0.010 inch unless otherwise specified.

TABLE 61.—DETAIL DIMENSIONS FOR ADJUSTABLE ADAPTER BODY
(In Inches at 68°F.)



Size	Length of Adapter	Diameter of Body and Major Diameter of External Acme Thread		Minor Diameter External Acme Thread	Threads per Inch	Length of Thread	Length of Flat	A.S.A. Taper No.	Machine Taper			
									Diameter of Taper Large End *G*		Taper per Foot	Length of Taper Socket
		Maximum	Minimum	Maximum					Maximum	Minimum		
S	*L*					*l*	*F*				*T*	*J*
3/4	3	0.7500	0.7497	0.6566	12	1 1/2	1 1/2	1	0.477	0.475	0.600	2 3/16
1 1/16	3 [illegible]	1.0625	1.0622	0.9691	12	1 5/8	1 7/8	1	0.477	0.475	0.600	2 3/16
1 1/16	3 [illegible]	1.0625	1.0622	0.9691	12	1 5/8	1 7/8	2	0.702	0.700	0.600	2 5/8
1 3/8	4 [illegible]	1.3750	1.3747	1.2816	12	1 7/8	2 5/8	2	0.702	0.700	0.600	2 5/8
1 3/8	4 [illegible]	1.3750	1.3747	1.2816	12	1 7/8	2 5/8	3	0.940	0.938	0.602	3 1/4
1 7/8	5 [illegible]	1.8750	1.8747	1.7816	12	2 1/8	3	3	0.940	0.938	0.602	3 1/4
1 7/8	5 [illegible]	1.8750	1.8747	1.7816	12	2 1/2	3	4	1.233	1.231	0.623	4 1/8

TABLE 61.—DETAIL DIMENSIONS FOR ADJUSTABLE ADAPTER BODY—*Continued*

Size	Distance End of Body to Keyway	Length of Drive Slot	Width of Drive Slot *M*		Distance End of Body to Center of Key	Woodruff Key Slot					Longitudinal Setscrew Slots	
						Nominal Size	Width, *W*		Depth, *h*		Width	Depth
			Maximum	Minimum			Maximum	Minimum	Maximum	Minimum		
S	*K*	*E*			*N*	*Z*					*P*	*U*
3/4	2 1/16	3/4	0.223	0.219	1/2	5/32 × 5/8	0.1568	0.1553	0.1719	0.1669	1/4	5/64
1 1/16	2 1/16	3/4	0.223	0.219	5/8	3/16 × 7/8	0.1880	0.1863	0.2813	0.2763	1/4	5/64
1 1/16	2 1/2	7/8	0.270	0.266	5/8	3/16 × 7/8	0.1880	0.1863	0.2813	0.2763	1/4	5/64
1 3/8	2 1/2	7/8	0.270	0.266	3/4	1/4 × 1	0.2505	0.2487	0.3130	0.3080	1/4	5/64
1 3/8	3 1/16	1 1/16	0.334	0.328	3/4	1/4 × 1	0.2505	0.2487	0.3130	0.3080	1/4	5/64
1 7/8	3 1/16	1 1/16	0.334	0.328	15/16	5/16 × 1 1/4	0 3130	0.3111	0.3908	0.3858	1/4	5/64
1 7/8	3 7/8	1 1/4	0.490	0.484	15/16	5/16 × 1 1/4	0.3130	0.3111	0.3908	0.3858	1/4	5/64

Centers. Shank end, internal center required.

Concentricity of Hole-G. Hole must run true with outside within 0.001 indicator reading.

Concentricity of Driving Slot-M. 0.219 to 0.270, inclusive = 0.006, indicator reading, 0.328 to 0.490, inclusive = 0.007 indicator reading.

Material. Chromium-nickel steel, S.A.E. 3120, or equivalent, case hardened.

Rockwell Hardness. C-50 to C-54.

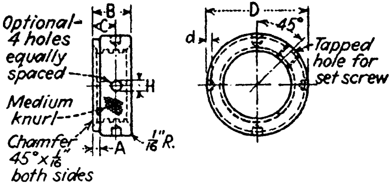
Finish. External diameter, major diameter of thread and internal diameter of tapered Hole-*G* must be ground, it being understood that finished surfaces must be acceptable to user.

Marking. Thread size, manufacturer's name, or trade mark, and A.S.A. taper number to be marked on end.

Manufacture. All burrs must be removed and thread must be polished. Tolerances on fractional dimensions are plus or minus 0.010 unless otherwise specified.

Screw-Thread Angle. The side of the acme screw thread shall make an angle of 14½ degrees with a line perpendicular to the axis of the thread.

TABLE 62.—GENERAL DIMENSIONS FOR ADJUSTABLE ADAPTER NUTS


Optional- 4 holes equally spaced
Medium knurl
Chamfer 45°×1/16" both sides
B
C
H
A
1/16" R.
D
d
45°
Tapped hole for set screw

Size	Diameter of Nut	Thickness			Setscrew Hole			Holes for Spanner Wrenches		Internal Acme Thread			
					Size	Pitch Diameter		Diameter	Depth	Minor Diameter		Major Diameter	Threads per Inch
						Maximum	Minimum			Maximum	Minimum	Minimum	
S	*D*	*B*	*C*	*A*				*H*	*d*				
3/4	1 1/4	1/2	1/4	1/32	5/16—18	0.2805	0.2764	1/4	1/8	0.670	0.667	0.751	12
1 1/16	1 9/16	1/2	1/4	1/16	5/16—18	0.2805	0.2764	1/4	1/8	0.982	0.979	1.063	12
1 3/8	1 7/8	1/2	1/4	1/16	5/16—18	0.2805	0.2764	1/4	1/8	1.294	1.291	1.376	12
1 7/8	2 5/8	3/4	3/8	3/32	5/16—18	0.2805	0.2764	1/4	3/16	1.795	1.792	1.876	12

Material. Chromium-nickel steel, S.A.E. 3120, or equivalent, case hardened.

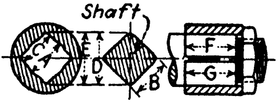
Finish. All surfaces must be finished.

Marking and Manufacture. Thread size, manufacturer's name or trade mark, and A.S.A. taper number should be placed on end. All burrs must be removed.

Tolerances. Tolerances on fractional dimensions are plus or minus 0.010 inch unless otherwise specified.

Screw-Thread Angle. The side of the acme screw thread shall make an angle of 14½ degrees with a line perpendicular to the axis of the thread.

TABLE 63.—PROPORTIONS OF SQUARE SHAFTS AND FIT ALLOWANCES



Nominal Diameter	Permanent Fit $\frac{B}{D} = 0.80$							Sliding Fit $\frac{B}{D} = 0.73$				
	A	*B*	*C*	*D*	*E*	*F*	*G*	*A*	*B*	*C*	*D*	*E*
1/4	0.193	0.189 0.188	0.187 0.186	0.250 0.245	0.260 0.252	5/16	3/8	0.257	0.248 0.247	0.250 0.249	0.344 0.339	0.354 0.346
3/8	0.290	0.283 0.282	0.281 0.280	0.375 0.370	0.385 0.377	7/16	1/2	0.386	0.373 0.372	0.375 0.374	0.516 0 511	0.526 0.518
1/2	0.386	0.377 0.376	0.375 0.374	0.500 0.495	0.510 0.502	11/16	3/4	33/64	0.498 0.497	0 500 0.499	0.687 0.682	0.697 0.689
5/8	33/64	0.502 0.501	0.500 0.499	0.625 0.620	0.635 0.627	11/16	3/4	41/64	0.623 0.622	0.625 0.624	0.844 0.839	0.854 0.846
3/4	37/64	0.564 0.563	0.562 0.561	0.750 0.745	0.760 0.752	13/16	1	49/64	0 748 0.747	0.750 0.749	1.031 1.026	1 051 1.036
7/8	45/64	0.689 0.688	0 687 0.686	0.875 0.870	0 885 0.877	1 1/8	1 1/4	29/32	0 873 0.872	0.875 0.874	1.187 1.182	1.207 1.192
1	27/32	0.815 0.814	0.812 0.811	1.000 0.995	1.020 1.005	1 3/8	1 1/2	1 1/32	0.998 0.997	1.000 0.999	1.375 1.370	1.395 1.380
1 1/8	29/32	0.878 0.877	0.875 0.874	1.125 1.120	1.145 1.130	1 3/8	1 1/2	1 5/32	1.123 1.122	1.125 1.124	1.562 1.557	1.582 1.567
1 1/4	1 1/32	1.103 1.102	1.000 0.999	1.250 1.245	1.270 1.255	1 3/8	1 1/2	1 9/32	1.248 1.247	1.250 1.249	1.687 1.682	1.707 1.692
1 3/8	1 5/32	1.128 1.127	1.125 1.124	1.375 1.370	1.395 1.380	1 7/8	2	1 27/64	1.373 1.372	1.375 1.374	1.875 1.870	1.895 1.880
1 1/2	1 5/32	1.128 1.127	1.125 1.124	1.500 1.495	1.520 1.505	1 7/8	2	1 35/64	1.498 1.497	1.500 1.499	2.062 2.057	2.082 2.067
1 3/4	1 27/64	1.378 1.377	1.375 1.374	1.750 1.745	1.770 1.755	2 1/8	2 1/4	1 13/16	1.748 1.747	1.750 1.749	2.375 2.370	2.395 2.380
2	1 35/64	1.504 1.503	1.500 1.498	2.000 1.995	2.020 2.005	2 7/8	3	2 1/16	1.997 1.996	2.000 1.998	2.750 2.745	2.770 2.755
2 1/4	1 13/16	1.754 1.753	1.750 1.748	2.250 2.245	2.270 2.255	2 7/8	3	2 5/16	2.247 2.246	2.250 2.248	3.062 3.057	3.082 3.067
2 1/2	2 1/16	2.004 2.003	2.000 1.998	2.500 2.495	2.520 2.505	3 3/8	3 1/2	2 37/64	2.497 2.496	2.500 2.498	3.437 3.432	3.457 3.442
2 3/4	2 5/16	2.254 2.253	2.250 2.248	2.750 2.745	2.770 2.755	3 3/8	3 1/2	2 53/64	2.747 2.746	2.750 2.748	3.750 3.745	3.770 3.755
3	2 37/64	2.504 2.503	2.500 2.498	3.000 2.995	3.020 3.005	3 7/8	4	3 3/32	2.997 2.996	3.000 2.998	4.125 4.120	4.145 4.130
3 1/2	2 53/64	2.754 2.753	2.750 2.748	3.500 3.459	3.520 3.505	4 3/8	4 1/2	3 39/64	3.497 3.496	3.500 3.498	4.750 4.745	4.770 4.755
4	3 21/64	3.254 3.253	3.250 3.248	3.495 3.995	4.020 4.005	5 3/8	5 1/2	4 1/8	3.997 3.996	4.000 3.998	5.500 5.495	5.520 5.505

Foote Brothers.

ACTUAL CUTTING SPEED OF PLANERS IN FEET PER MINUTE

Forward Cutting Speed in Feet per Minute	Return Speed				
	4 to 1	5 to 1	6 to 1	7 to 1	8 to 1
20	16	16.66	17.14	17.5	17.76
25	20	20.83	21.42	21.87	22.16
30	24	25.	25.71	26.25	26.56
35	28	29.16	30.	30.62	31.04
40	32	33.33	34.28	35.	35.52
45	36	37.5	38.56	39.37	40.
50	40	41.66	42.84	43.75	44.48
55	44	45.83	47.12	48.12	48.95
60	48	50.	51.42	52.50	53.43
65	52	54.16	55.70	56.87	57.91
70	56	58.33	60.	61.25	62.3
75	60	62.5	64.28	66.62	66.71

The table shows clearly that a slight increase in cutting speed is better than high return speed. A 25-foot forward speed at 4 to 1 return is much better than 8 to 1 return with 20-feet forward speed. Economical planer speeds are given below (Cincinnati Planer Co.).

Cast Iron roughing . . . 40 to 50 ft.; finishing . . . 30 to 40 ft.

Steel casting and wrought iron roughing 40 to 45 ft.; finishing 30 to 40 ft.

Bronze and brass . . . 50 to 75 ft.; Machinery steel . . . 30 to 45 ft.

ALLOWANCES FOR BOLTHEADS AND UPSETS

Stock Allowed for Standard Upsets by Acme Machinery Company

½	in. Upset to	⅝	in. Length of Upset,	3	in. Stock required,	1¾	in.
⅝	“ “	¾	“ “ “	3½	“ “ “	1⅝	“
¾	“ . “	⅞	“ “ “	3½	“ “ “	1½	“
⅞	“ “	1⅛	“ “ “	4	“ “ “	2¾	“
1	“ “	1¼	“ “ “	4	“ “ “	2⅝	“
1⅛	“ “	1⅜	“ “ “	4½	“ “ “	2¼	“
1¼	“ “	1½	“ “ “	4½	“ “ “	2½	“
1⅜	“ “	1⅝	“ “ “	5	“ “ “	2⅛	“
1½	“ “	1¾	“ “ “	5	“ “ “	2	“
1½	“ “	1⅞	“ “ “	5	“ “ “	2⅞	“
1⅝	“ “	1⅞	“ “ “	5½	“ “ “	1⅞	“
1¾	“ “	2	“ “ “	5½	“ “ “	1¾	“
1⅞	“ “	2⅛	“ “ “	6	“ “ “	2	“
2	“ “	2⅜	“ “ “	6	“ “ “	2½	“
2	“ “	2½	“ “ “	6	“ “ “	3½	“
2¼	“ “	2⅝	“ “ “	6½	“ “ “	2½	“
2½	“ “	2⅞	“ “ “	6½	“ “ “	2¼	“
2¾	“ , “	3⅛	“ “ “	7	“ “ “	2	“
3	“ “	3½	“ “ “	7	“ “ “	2⅝	“

Table of Board Feet in Pieces 1 to 24 Inches Wide Up to 24 Feet Long

The table herewith shows the board feet contained in planks of a given width and length. This table is of use especially to the patternmaker but may be of value to any one having to make calculations in board measure.

Width of Board in Inches	Length of Board in Feet																			
	1′	2′	3′	4′	5′	6′	7′	8′	9′	10′	11′	12′	13′	14′	15′	16′	18′	20′	22′	24′
1″	1/12	1/6	1/4	1/3	5/12	1/2	7/12	2/3	3/4	5/6	11/12	1	1 1/12	1 1/6	1 1/4	1 1/3	1 1/2	1 2/3	1 5/6	2
2″	1/6	1/3	1/2	2/3	5/6	1	1 1/6	1 1/3	1 1/2	1 2/3	1 5/6	2	2 1/6	2 1/3	2 1/2	2 2/3	3	3 1/3	3 2/3	4
3″	1/4	1/2	3/4	1	1 1/4	1 1/2	1 3/4	2	2 1/4	2 1/2	2 3/4	3	3 1/4	3 1/2	3 3/4	4	4 1/2	5	5 1/2	6
4″	1/3	2/3	1	1 1/3	1 2/3	2	2 1/3	2 2/3	3	3 1/3	3 2/3	4	4 1/3	4 2/3	5	5 1/3	6	6 2/3	7 1/3	8
5″	5/12	5/6	1 1/4	1 2/3	2 1/12	2 1/2	2 11/12	3 1/3	3 3/4	4 1/6	4 7/12	5	5 5/12	5 5/6	6 1/4	6 2/3	7 1/2	8 1/3	9 1/6	10
6″	1/2	1	1 1/2	2	2 1/2	3	3 1/2	4	4 1/2	5	5 1/2	6	6 1/2	7	7 1/2	8	9	10	11	12
7″	7/12	1 1/6	1 3/4	2 1/3	2 11/12	3 1/2	4 1/12	4 2/3	5 1/4	5 5/6	6 5/12	7	7 7/12	8 1/6	8 3/4	9 1/3	10 1/2	11 2/3	12 5/6	14
8″	2/3	1 1/3	2	2 2/3	3 1/3	4	4 2/3	5 1/3	6	6 2/3	7 1/3	8	8 2/3	9 1/3	10	10 2/3	12	13 1/3	14 2/3	16
9″	3/4	1 1/2	2 1/4	3	3 3/4	4 1/2	5 1/4	6	6 3/4	7 1/2	8 1/4	9	9 3/4	10 1/2	11 1/4	12	13 1/2	15	16 1/2	18
10″	5/6	1 2/3	2 1/2	3 1/3	4 1/6	5	5 5/6	6 2/3	7 1/2	8 1/3	9 1/6	10	10 5/6	11 2/3	12 1/2	13 1/3	15	16 2/3	18 1/3	20
11″	11/12	1 5/6	2 3/4	3 2/3	4 7/12	5 1/2	6 5/12	7 1/3	8 1/4	9 1/6	10 1/12	11	11 11/12	12 5/6	13 3/4	14 2/3	16 1/2	18 1/3	20 1/6	22
12″	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	18	20	22	24
13″	1 1/12	2 1/6	3 1/4	4 1/3	5 5/12	6 1/2	7 7/12	8 2/3	9 3/4	10 5/6	11 11/12	13	14 1/12	15 1/6	16 1/4	17 1/3	19 1/2	21 2/3	23 5/6	26
14″	1 1/6	2 1/3	3 1/2	4 2/3	5 5/6	7	8 1/6	9 1/3	10 1/2	11 2/3	12 5/6	14	15 1/6	16 1/3	17 1/2	18 2/3	21	23 1/3	25 2/3	28
15″	1 1/4	2 1/2	3 3/4	5	6 1/4	7 1/2	8 3/4	10	11 1/4	12 1/2	13 3/4	15	16 1/4	17 1/2	18 3/4	20	22 1/2	25	27 1/2	30
16″	1 1/3	2 2/3	4	5 1/3	6 2/3	8	9 1/3	10 2/3	12	13 1/3	14 2/3	16	17 1/3	18 2/3	20	21 1/3	24	26 2/3	29 1/3	32
17″	1 5/12	2 5/6	4 1/4	5 2/3	7 1/12	8 1/2	9 11/12	11 1/3	12 3/4	14 1/6	15 7/12	17	18 5/12	19 5/6	21 1/4	22 2/3	25 1/2	28 1/3	31 1/6	34
18″	1 1/2	3	4 1/2	6	7 1/2	9	10 1/2	12	13 1/2	15	16 1/2	18	19 1/2	21	22 1/2	24	27	30	33	36
19″	1 7/12	3 1/6	4 3/4	6 1/3	7 11/12	9 1/2	11 1/12	12 2/3	14 1/4	15 5/6	17 5/12	19	20 7/12	22 1/6	23 3/4	25 1/3	28 1/2	31 2/3	34 5/6	38
20″	1 2/3	3 1/3	5	6 2/3	8 1/3	10	11 2/3	13 1/3	15	16 2/3	18 1/3	20	21 2/3	23 1/3	25	26 2/3	30	33 1/3	36 2/3	40
21″	1 3/4	3 1/2	5 1/4	7	8 3/4	10 1/2	12 1/4	14	15 3/4	17 1/2	19 1/4	21	22 3/4	24 1/2	26 1/4	28	31 1/2	35	38 1/2	42
22″	1 5/6	3 2/3	5 1/2	7 1/3	9 1/6	11	12 5/6	14 2/3	16 1/2	18 1/3	20 1/6	22	23 5/6	25 2/3	27 1/2	29 1/3	33	36 2/3	40 1/3	44
23″	1 11/12	3 5/6	5 3/4	7 2/3	9 7/12	11 1/2	13 5/12	15 1/3	17 1/4	19 1/6	21 1/12	23	24 11/12	26 5/6	28 3/4	30 2/3	34 1/2	38 1/3	42 1/6	46
24″	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	36	40	44	48

Table gives board feet in an inch thick plank. For other thicknesses multiply by thickness in inches.

QUICK WAY OF ESTIMATING LUMBER FOR A PATTERN

MULTIPLY length, breadth, and thickness in inches together and this by 7, pointing off three places.

Board 8 inches wide, 18 inches long, 1 inch thick. 8 × 18 × 1 × 7 = 1.008 square feet. This is .008 too much, but near enough for most work. Board 1½ × 10 × 36 = 540 × 7 = 3.780. The correct answer is 3.75.

TABLE GIVING PROPORTIONATE WEIGHT OF CASTINGS TO WEIGHT OF WOOD PATTERNS

A Pattern Weighing One Pound Made of (Less weight of Core Prints)	Cast Iron	Brass	Copper	Bronze	Bell Metal	Zinc
Pine or Fir..	16	18.8	19.7	19.3	17	15.5
Oak........	9	10.1	10.4	10.3	10.9	8.6
Beech	9.7	10.9	11.4	11.3	11.9	9.1
Linden	13.4	15.1	16.7	15.5	16.3	12.9
Pear........	10.2	11.5	11.9	11.8	12.4	9.8
Birch.... ..	10.6	11.9	12.3	12.2	12.9	10.2
Alder.......	12.8	14.3	14.9	14.7	15.5	12.2
Mahogany ..	11.7	13.2	13.7	13.5	14.2	11.2
Brass.......	0.85	0.95	0.99	0.98	1.0	0.81

DEGREES OBTAINED BY OPENING A TWO-FOOT RULE

Degrees	Inches	Degrees	Inches	Degrees	Inches
1	.21	15	3.12	55	11.08
2	.422	20	4.17	60	12
3	.633	25	5.21	65	12.89
4	.837	30	6.21	70	13.76
5	1.04	35	7.20	75	14.61
7.5	1.57	40	8.21	80	15.43
10	2.09	45	9.20	85	16.21
14.5	3.015	50	10.12	90	16.97

Open a two-foot rule until open ends are distance apart given in table when degrees given in table can be scribed. Same results can be had with two 12-inch steel scales placed together at one end.

WEIGHT OF FILLETS

To facilitate the calculations of the weights of the different parts of a machine from the drawings, the accompanying table of areas or volumes of fillets having radii from $\frac{1}{16}$ to 3 inches can be used. It has been calculated for fillets connecting sides that are at right angles to each other.

TABLE OF AREAS OR VOLUMES OF FILLETS

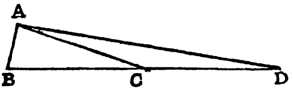
Radius of Fillet in Inches	Area or Volume of Fillet in Sq. or Cubic Inches	Radius of Fillet in Inches	Area or Volume of Fillet in Sq. or Cubic Inches
1/16	.0008	1 9/16	.5240
1/8	.0033	1 5/8	.5667
3/16	.0075	1 11/16	.6119
1/4	.0134	1 3/4	.6572
5/16	.0209	1 13/16	.7050
3/8	.0302	1 7/8	.7543
7/16	.0410	1 15/16	.8056
1/2	.0537	2	.8584
9/16	.0678	2 1/16	.9129
5/8	.0838	2 1/8	.9690
11/16	.1013	2 3/16	1.0269
3/4	.1207	2 1/4	1.0864
13/16	.1417	2 5/16	1.1475
7/8	.1643	2 3/8	1.2105
15/16	.1886	2 7/16	1.2749
1	.2146	2 1/2	1.3413
1 1/16	.2423	2 9/16	1.4086
1 1/8	.2716	2 5/8	1.4787
1 3/16	.3026	2 11/16	1.5500
1 1/4	.3353	2 3/4	1.6229
1 5/16	.3697	2 13/16	1.6869
1 3/8	.4057	2 7/8	1.7739
1 7/16	.4434	2 15/16	1.8518
1 1/2	.4829	3	1.9314

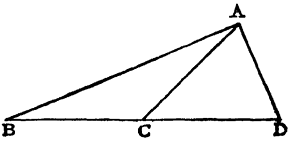
To find the volume of a fillet by this table when the radius and length are given, multiply the value in the table opposite the given radius by the length of the fillet in inches, and this result multiplied by the weight of a cubic inch of the material will give the weight of the fillet.

LAYING OUT A SQUARE CORNER

It sometimes happens that we wish to lay out a perfectly square corner and have no square of any kind handy. Here is a way that requires nothing but a scale or rule, or even a straight stick without any graduations whatever will do. Using this stick, draw a line as *AC* (in left-hand accompanying figure), and at one end of this draw the line *BD* at any angle. This line must be straight, twice as long as *AC* and of equal length each side of the point *C*. Then, if you join points *DAB*, you have an exact right angle of square corner.

The right-hand accompanying figure is simply another example of this, in which the line *AC* has been drawn at a very different angle to show that it works in any position. Joining the ends *DAB* as before also gives an exact right angle.





Another Method

Another method is by what is known as the "6, 8, and 10 rule." This means that if a triangle has sides in the ratio of 6, 8, and 10, the angle is 90 degrees. Lay down a line 6 units long, either inches, feet, or yards. Lay off another line 8 units long as nearly right angles as possible. Measure across the ends of the two lines and adjust until this distance is 10 units, which makes it a right angle. These distances may be 3, 4, and 5 or 12, 16, and 20, or any combination in this ratio. It is largely used in laying out large corners.

Table Showing Volumes and Radii of Spheres Having Capacities of ¼ Pint and $\frac{1}{10}$ Liter and Multiplies Thereof

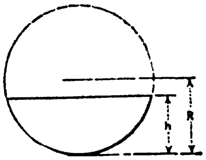
Pints	Volume in Cubic Inches	Radius of Sphere in Inches	Liters	Volume in Cubic Inches	Radius of Sphere in Inches
0.25	7.21875	1.1989	0.1	6.10302	1.1290
0.50	14.43750	1.5105	0.2	12.20604	1.4280
0.75	21.65625	1.7291	0.3	18.30906	1.6350
1.00	28.87500	1.9031	0.4	24.41208	1.7910
1.25	36.09375	2.0501	0.5	30.51510	1.9383
1.50	43.31250	2.1785	0.6	36.61812	2.0600
1.75	50.53125	2.2934	0.7	42.72114	2.1836
2.00	57.75000	2.3978	0.8	48.82416	2.2673
2.25	64.96875	2.4938	0.9	54.92718	2.3581
2.50	72.18750	2.5838	1.0	61.03020	2.4424
2.75	79.10625	2.6664	1.1	67.13322	2.5213
3.00	86.62500	2.7423	1.2	73.23624	2.5954
3.25	93.84375	2.8197	1.3	79.33926	2.6656
3.50	101.06250	2.8895	1.4	85.44228	2.7322
3.75	108.28125	2.9566	1.5	91.54530	2.7936
4.00	115.50000	3.0211	1.6	97.64832	2.8566
4.25	122.71875	3.0827	1.7	103.75134	2.9149
4.50	129.93750	3.1420	1.8	109.85436	2.9716
4.75	137.15625	3.1992	1.9	115.95738	3.0252
5.00	144.37500	3.2543	2.0	122.06040	3.0772
5.25	151.59375	3.3077	2.1	128.16342	3.1275
5.50	158.81250	3.3594	2.2	134.26644	3.1765
5.75	166.03125	3.4095	2.3	140.36946	3.2240
6.00	173.25000	3.4583	2.4	146.47248	3.2700
6.25	180.46875	3.5056	2.5	152.57550	3.3148
6.50	187.68750	3.5518	2.6	158.67852	3.3584
6.75	194.90625	3.5967	2.7	164.78154	3.4010
7.00	202.12500	3.6406	2.8	170.88456	3.4424
7.25	209.34375	3.6834	2.9	176.98758	3.4830
7.50	216.56250	3.7253	3.0	183.09060	3.5226
7.75	223.78125	3.7662	3.1	189.19362	3.5613
8.00	231.00000	3.8063	3.2	195.29664	3.5991
			3.3	201.39966	3.6363
			3.4	207.50268	3.6725
			3.5	213.60570	3.7082
			3.6	219.70872	3.7432
			3.7	225.81174	3.7775
			3.8	231.91476	3.8113
			3 9	238.01778	3.8445
			4.0	244.12080	3.8770

Volume of sphere $= \frac{4}{3}\pi r^3$

$\pi = 3.141592$

$\frac{4}{3}\pi = 4.18879$

1 liter = 0.2642 U. S. gallon or 1.0568 quarts



h = height of segment   R = radius of sphere

Determine $\frac{h}{R}$ from data at hand

To find volume of segment:

Method A.—Multiply volume of sphere by number opposite under Relative Volume

Method B.—Multiply R^3 by number opposite $\frac{h}{R}$ under Volume, R = Unity

Method C.—Find logarithm of R, multiply log by 3 and add to this the number opposite $\frac{h}{R}$ under Log V, R = Unity. Find number for this logarithm.

Volume of sphere $\frac{4}{3}\pi R^3$

Volume of segment $= \frac{1}{3}\pi h2(3R - h)$

Volume of Spherical Segments

R	Relative Volume	Volume, R = Unity	Log R = Unity	$\frac{h}{R}$	Relative Volume	Volume, R = Unity	Log R = Unity
0.01	0.00007475	0.00031311	6.495700	0.51	0.16191225	0.678216	9.831368
0.02	0.000298	0.00124826	7.096305	0.52	0.167648	0.702243	9.846488
0.03	0.00066825	0.00279916	7.447028	0.53	0.17345575	0.726571	9.861278
0.04	0.001184	0.00495953	7.695441	0.54	0.179334	0.751193	9.875752
0.05	0.00184375	0.00772308	7.887791	0.55	0.18528125	0.776104	9.889920
0.06	0.002646	0.01108355	8.044697	0.56	0.191296	0.801300	9.903795
0.07	0.00358925	0.0150346	8.177093	0.57	0.19737675	0.826771	9.917385
0.08	0.004672	0.0195700	8.291592	0.58	0.203522	0.852251	9.930700
0.09	0.00589275	0.0246835	8.392407	0.59	0.20973025	0.878515	9.943750
0.10	0.00725	0.0303688	8.482427	0.60	0.216	0.904779	9.956543
0.11	0.00874225	0.0366195	8.563712	0.61	0.22232975	0.931293	9.969087
0.12	0.010368	0.0434293	8.637783	0.62	0.228718	0.958053	9.981389
0.13	0.01212575	0.0507923	8.705798	0.63	0.23516225	0.985050	9.993458
0.14	0.014014	0.0587017	8.768651	0.64	0.241664	1.011581	0.005301
0.15	0.01603125	0.0671502	8.827057	0.65	0.24821875	1.039738	0.016924
0.16	0.018176	0.0761354	8.881587	0.66	0.254826	1.067414	0.028333
0.17	0.02044675	0.0856772	8.932713	0.67	0.26148425	1.095305	0.039535
0.18	0.022842	0.0956804	8.980823	0.68	0.268192	1.123400	0.050535
0.19	0.02536025	0.1062288	9.026242	0.69	0.27494775	1.151700	0.061340
0.20	0.028	0.1172863	9.069247	0.70	0.28175	1.180193	0.021953

0.21	0.03075975	0.128846	9.110072	0.71	0.28859725	1.208875	0.082381
0.22	0.033638	0.140903	9.148919	0.72	0.295488	1.237738	0.092629
0.23	0.03663325	0.153449	9.185965	0.73	0.30242075	1.266780	0.102701
0.24	0.039744	0.166480	9.221360	0.74	0.309394	1.295985	0.112500
0.25	0.04296875	0.1177987	9.255242	0.75	0.31640625	1.325363	0.122335
0.26	0.046306	0.193967	9.287727	0.76	0.323456	1.354890	0.131904
0.27	0.04975425	0.208410	9.318920	0.77	0.33054175	1.384570	0.141315
0.28	0.053312	0.223313	9.348914	0.78	0.337662	1.414397	0.150571
0.29	0.05697775	0.238667	9.377794	0.79	0.34481525	1.444359	0.150675
0.30	0.06075	0.254469	9.405635	0.80	0.352	1.474459	0.168632
0.31	0.06462725	0.270710	9.432504	0.81	0.35921475	1.504678	0.177443
0.32	0.068608	0.287385	9.548464	0.82	0.366458	1.535011	0.186113
0.33	0.07269075	0.304486	9.483568	0.83	0.37372825	1.565471	0.194645
0.34	0.076874	0.322009	9.507869	0.84	0.381024	1.596030	0.203042
0.35	0.08115625	0.399947	9.531411	0.85	0.38834375	1.626697	0.211307
0.36	0.085536	0.358293	9.554238	0.86	0.395686	1.657446	0.219440
0.37	0.09001175	0.377040	9.576388	0.87	0.40304925	1.688289	0.227447
0.38	0.94582	0.396184	9.597897	0.88	0.410432	1.719214	0.235330
0.39	0.09924525	0.415718	9.618799	0.89	0.41783275	1.750210	0.243091
0.40	0.104	0.435634	9.639122	0.90	0.42525	1.781283	0.250733
0.41	0.10884475	0.445928	9.658897	0.91	0.4326825	1.812417	0.258258
0.42	0.113778	0.476593	9.678148	0.92	0.440128	1.843606	0.265668
0.43	0.11879825	0.407621	9.696899	0.93	0.44758475	1.874845	0.272965
0.44	0.123904	0.519008	9.715174	0.94	0.455054	1.906127	0.280152
0.45	0.12909375	0.540747	9.732994	0.95	0.46253125	1.937445	0.287230
0.46	0.134366	0.562832	9.750379	0.96	0.470016	1.968798	0.294201
0.47	0.13971925	0.585256	9.767346	0.97	0.477750675	2.000175	0.301068
0.48	0.145152	0.608011	9.783912	0.98	0.485002	2.031570	0.307832
0.49	0.15066275	0.631096	9.800095	0.99	0.49250025	2.062982	0.314495
0.50	0.15625	0.654498	9.815909	1.00	0.5	2.094397	0.321059

CAPACITY OF ROUND VERTICAL TANKS IN U. S. GALLONS FOR ONE FOOT IN DEPTH

Dia. of Tanks Ft.	In.	No. U. S. Gals.	Cu. Ft. and Area in Sq. Ft.	Dia. of Tanks Ft.	In.	No. U. S. Gals.	Cu. Ft. and Area in Sq. Ft.	Dia. of Tanks Ft.	In.	No. U. S. Gals.	Cu. Ft. and Area in Sq. Ft.
1		5.87	0.785	5	8	188.66	25.22	19		2120.90	283.53
1	1	6.89	0.922	5	9	194.25	25.97	19	3	2177.10	291.04
1	2	8.00	1.069	5	10	199 92	26.73	19	6	2234.00	298.65
1	3	9.18	1.227	5	11	205.67	27.49	19	9	2291.70	306.35
1	4	10.44	1.396	6		211.51	28.27	20		2350.10	314.16
1	5	11.79	1.576	6	3	229.50	30.68	20	3	2409.20	322.06
1	6	13.22	1.767	6	6	248.23	33.18	20	6	2469.10	330.06
1	7	14.73	1.969	6	9	267.69	35.78	20	9	2529.60	338.16
1	8	16.32	2.182	7		287.88	38.48	21		2591.00	346.36
1	9	17.99	2.405	7	3	308.81	41.28	21	3	2653.00	354.66
1	10	19.75	2.640	7	6	330.48	44.18	21	6	2715.80	363.05
1	11	21.58	2.885	7	9	352.88	47.17	21	9	2779.30	371.54
2		23.50	3.142	8		376.01	50.27	22		2843.60	380.13
2	1	25.50	3.409	8	3	399.88	53.46	22	3	2908.60	388.82
2	2	27.58	3.687	8	6	424.48	56.75	22	6	2974.30	397.61
2	3	29.74	3.976	8	9	449.82	60.13	22	9	3040.80	406.49
2	4	31.99	4.276	9		475.89	63.62	23		3108.00	415.48
2	5	34.31	4.587	9	3	502.70	67.20	23	3	3175.90	424.56
2	6	36.72	4.909	9	6	530.24	70.88	23	6	3244.60	433.74
2	7	39.21	5.241	9	9	558.51	74.66	23	9	3314.00	443.01
2	8	41.78	5.585	10		587.52	78.54	24		3384.10	452.39
2	9	44.43	5.940	10	3	617.26	82.52	24	3	3455.00	461.86
2	10	47.16	6.305	10	6	640.74	86.59	24	6	3526.60	471.44
2	11	49.98	6.681	10	9	678.95	90.76	24	9	3598.90	481.11
3		52.88	7.069	11		710.90	95.03	25		3672.00	490.87
3	1	55.86	7.467	11	3	743.58	99.40	25	3	3745.80	500.74
2	2	58.92	7.876	11	6	776.99	103.87	25	6	3820.30	510.71
3	3	62.06	8.296	11	9	811.14	108.43	25	9	3895.60	520.77
3	4	65.28	8.727	12		846.03	113.10	26		3971.60	530.93
3	5	68.58	9.168	12	3	881.65	117.86	26	3	4048.40	541.19
3	6	71.97	9.621	12	6	918.00	122.72	26	6	4125.90	551.55
3	7	75.44	10.085	12	9	955.09	127.68	26	9	4204.10	562.
3	8	78.99	10.559	13		992.91	132.73	27		4283.00	572.66
3	9	82.62	11.045	13	3	1031.50	137.89	27	3	4362.70	583.21
3	10	86.33	11.541	13	6	1070.80	143.14	27	6	4443.10	593.96
3	11	90.13	12.048	13	9	1110.80	148.49	27	9	4525.30	604.81
4		94.00	12.566	14		1151.50	153.94	28		4606.20	615.75
4	1	97.96	13.095	14	3	1193.00	159.48	28	3	4688.80	626.80
4	2	102.00	13.635	14	6	1235.30	165.13	28	6	4772.10	637.94
4	3	106.12	14.186	14	9	1278.20	170.87	28	9	4856.20	649.18
4	4	110.32	14.748	15		1321.90	176.71	29		4941.00	660.52
4	5	114.61	15.321	15	3	1366.40	182.65	29	3	5026.60	671.96
4	6	118.97	15.90	15	6	1411.50	188.69	29	6	5122.90	683.49
4	7	123.42	16.50	15	9	1457.40	194.83	29	9	5199.90	695.13
4	8	127.95	17.10	16		1504.10	201.06	30		5287.70	706.86
4	9	132.56	17.72	16	3	1551.40	207.39	30	3	5376.20	718.69
4	10	137.25	18.35	16	6	1599.50	213.82	30	6	5465.40	730.62
4	11	142.02	18.99	16	9	1648.40	220.35	30	9	5555.40	742.64
5		146.88	19.63	17		1697.90	226.98	31		5646.10	754.77
5	1	151.82	20.29	17	3	1748.20	233.71	31	3	5773.50	766.99
5	2	156.83	20.97	17	6	1799.30	240.53	31	6	5829.70	779.31
5	3	161.93	21.65	17	9	1851.10	247.45	31	9	5922.60	791.73
5	4	167.12	22.34	18		1903.60	254.47	32		6016.20	804.25
5	5	172.38	23.04	18	3	1956.80	261.59	32	3	6110.60	816.86
5	6	177.72	23.76	18	6	2010.80	268.80	32	6	6205.70	829.58
5	7	183.15	24.48	18	9	2065.50	276.12	32	9	6301.50	842.39

31½ Gallons = 1 Barrel

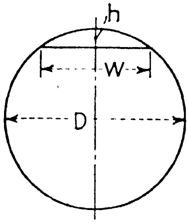
To find the capacity of tanks greater than the largest given in the table, look in the table for a tank of one-half of the given size and multiply by 4, or one of one-third its size and multiply its capacity by 9, etc.

HEIGHTS AND WIDTHS OF CIRCULAR SEGMENTS

The table that follows is computed for circles of 1 inch diameter. For other diameters convert width of flat into corresponding width for 1 inch diameter. Thus a 1 inch width of flat or chord on a 2 inch diameter circle would become ½ inch on a diameter of 1 inch. Refer to table and opposite 0.5000 in column under *W*, find 0.067 as height of segment—or depth of flat—for 1 inch diameter. Multiply this by 2 inches and get 0.134 inch as depth from top of arc, or height from flat to top of circle.

$$W = 2\sqrt{h(D - h)} \qquad h = \tfrac{1}{2}(D - \sqrt{D^2 - W^2})$$

Or if a special keyway (not found in Table 38 on page 893) is desired, say a keyway 1½ inch wide in a 4-inch shaft, we find dividing 1½ by 4 that we have a corresponding flat for 1-inch shaft of 1½ divided by 4 or 0.375. In the table under *W* we interpolate between the values for 0.3724 and 0.3772 (a difference of 0.0048) and find the corresponding depth would be 0.0365 for a 1-inch shaft. Multiplying by 4 gives a depth of 0.1460 for drop from top of 4-inch shaft.



HEIGHTS AND WIDTHS OF CIRCULAR SEGMENTS

h	*W*	*h*	*W*	*h*	*W*	*h*	*W*	*h*	*W*
0.001	0.0628	0.051	0.4400	0.101	0.6027	0.151	0.7161	0.201	0.8015
0.002	0.0895	0.052	0.4441	0.102	0.6053	0.152	0.7181	0.202	0.8030
0.003	0.1095	0.053	0.4480	0.103	0.6081	0.153	0.7200	0.203	0.8045
0.004	0.1262	0.054	0.4519	0.104	0.6106	0.154	0.7220	0.204	0.8060
0.005	0.1412	0.055	0.4561	0.105	0.6131	0.155	0.7240	0.205	0.8074
0.006	0.1544	0.056	0.4601	0.106	0 6167	0.156	0.7258	0.206	0.8090
0.007	0.1668	0.057	0.4636	0.107	0.6182	0.157	0.7278	0.207	0.8104
0.008	0.1783	0.058	0.4677	0.108	0.6209	0.158	0.7296	0.208	0.8117
0.009	0.1888	0.059	0.4713	0.109	0.6234	0.159	0.7314	0.209	0.8131
0.010	0.1990	0.060	0.4749	0.110	0.6259	0.160	0.7331	0.210	0.8146
0.011	0.2087	0.061	0.4787	0.111	0.6284	0.161	0.7351	0.211	0.8160
0.012	0.2179	0.062	0.4822	0.112	0.6307	0.162	0.7370	0.212	0.8175
0.013	0.2267	0.063	0.4858	0.113	0.6336	0.163	0.7388	0.213	0.8190
0.014	0.2349	0.064	0.4896	0.114	0.6356	0.164	0.7406	0.214	0.8202
0.015	0.2431	0.065	0.4930	0.115	0.6381	0.165	0.7425	0.215	0.8217
0.016	0.2509	0.066	0.4965	0.118	0.6401	0.166	0.7441	0.216	0.9230
0.017	0.2585	0.067	0.5000	0.117	0.6430	0.167	0.7461	0.217	0.8246
0.018	0.2661	0.068	0.5033	0.118	0.6452	0.168	0.7480	0.218	0.8258
0.019	0.2730	0.069	0.5067	0.119	0.6480	0.169	0.7495	0.219	0.8271
0.020	0.2801	0.070	0.5103	0.120	0.6500	0.170	0.7513	0.220	0.8286

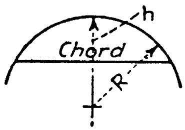
Heights and Widths of Circular Segments.—*Continued*

h	*W*	*h*	*W*	*h*	*W*	*h*	*W*	*h*	*W*
0.021	0.2868	0.071	0.5136	0.121	0.6525	0.171	0.7532	0.221	0.8300
0.022	0.2935	0.072	0.5168	0.122	0.6547	0.172	0.7548	0.222	0.8311
0.023	0.3000	0.073	0.5203	0.123	0.6570	0.173	0.7566	0.223	0.8326
0.024	0.3063	0.074	0.5237	0.124	0.6591	0.174	0.7581	0.224	0.8339
0.025	0.3121	0.075	0.5267	0.125	0.6615	0.175	0.7600	0.225	0.8351
0.026	0.3184	0.076	0.5300	0.126	0.6637	0.176	0.7617	0.226	0.8364
0.027	0.3239	0.077	0.5331	0.127	0.6660	0.177	0.7634	0.227	0.8375
0.028	0.3300	0.078	0.5363	0.128	0.6683	0.178	0.7651	0.228	0.8391
0.029	0.3357	0.079	0.5395	0.129	0.6704	0.179	0.7666	0.229	0.8404
0.030	0.3412	0.080	0.5424	0.130	0.6728	0.180	0.7685	0.230	0.8417
0.031	0.3466	0.081	0.5458	0.131	0.6750	0.181	0.7700	0.231	0.8431
0.032	0.3521	0.082	0.5488	0.132	0.6771	0.182	0.7717	0.232	0.8443
0.033	0.3573	0.083	0.5520	0.133	0.6792	0.183	0.7735	0.233	0.8456
0.034	0.3624	0.084	0.5548	0.134	0.6814	0.184	0.7750	0.234	0.8470
0.035	0.3676	0.085	0.5578	0.135	0.6835	0.185	0.7766	0.235	0.8480
0.036	0.3724	0.086	0.5606	0.136	0.6857	0.186	0.7782	0.236	0.8493
0.037	0.3772	0.087	0.5638	0.137	0.6897	0.187	0.7799	0.237	0.8505
0.038	0.3824	0.088	0.5666	0.138	0.6898	0.188	0.7815	0.230	0.8515
0.039	0.3873	0.089	0.5695	0.139	0.6920	0.189	0.7831	0.239	0.8530
0.040	0.3920	0.090	0.5724	0.140	0.6940	0.190	0.7846	0.240	0.8541
0.041	0.3966	0.091	0.5752	0.141	0.6961	0.191	0.7862	0.241	0.8554
0.042	0.4011	0.092	0.5780	0.142	0.6982	0.192	0.7880	0.242	0.8566
0.043	0.4060	0.093	0.5810	0.143	0.7000	0.193	0.7892	0.243	0.8578
0.44	0.4102	0.094	0.5838	0.144	0.7024	0.194	0.7909	0.244	0.8590
0.045	0.4148	0.095	0.5866	0.145	0.7042	0.195	0.7925	0.245	0.8602
0.046	0.4190	0.096	0.5892	0.146	0.7063	0.196	0.7940	0.246	0.8613
0.047	0.4232	0.097	0.5920	0.147	0.7080	0.187	0.7955	0.247	0.8626
0.048	0.4276	0.098	0.5946	0.148	0.7102	0.198	0.7971	0.248	0.8637
0.049	0.4318	0.099	0.5974	0.149	0.7122	0.199	0.7985	0.249	0.8649
0.050	0.4358	0.100	0.6001	0.150	0.7141	0.200	0.8000	0.250	0.8660
0.251	0.8672	0.301	0.9174	0.351	0.9546	0.401	0.9802	0.451	0.9952
0.252	0.8683	0.302	0.9183	0.352	0.9552	0.402	0.9806	0.452	0.9954
0.253	0.8695	0.303	0.9191	0.353	0.9558	0.403	0.9810	0.453	0.9956
0.254	0.8706	0.304	0.9200	0.354	0.9565	0.404	0.9814	0.454	0.9958
0.255	0.8718	0.305	0.9209	0.355	0.9571	0.405	0.9818	0.455	0.9960
0.256	0.8730	0.306	0.9217	0.356	0.9577	0.406	0.9822	0.456	0.9962
0.257	0.8740	0.307	0.9225	0.357	0.9982	0.407	0.9826	0.457	0.9963
0.258	0.8750	0.308	0.9233	0.358	0.9589	0.408	0.9830	0.458	0.9965
0.259	0.8762	0.309	0.9242	0.359	0.9594	0.409	0.9833	0.459	0.9966
0.260	0.8772	0.310	0.9250	0.360	0.9600	0.410	0.9837	0.460	0.9968
0.261	0.8784	0.311	0.9259	0.361	0.9606	0.411	0.9840	0.461	0.9969
0.262	0.8794	0.312	0.9266	0.362	0.9612	0.412	0.9844	0.462	0.9971
0.263	0.8805	0.313	0.9274	0.363	0.9617	0.413	0.9847	0.463	0.9972
0.264	0.8816	0.314	0.9282	0.364	0.9623	0.414	0.9851	0.464	0.9974
0.265	0.8827	0.315	0.9290	0.365	0.9629	0.415	0.9855	0.465	0.9975
0.266	0.8838	0.316	0.9299	0.366	0.9634	0.416	0.9858	0.466	0.9977
0.267	0.8848	0.317	0.9306	0.367	0.9640	0.417	0.9861	0.467	0.9978
0.268	0.8858	0.318	0.9315	0.368	0.9645	0.418	0.9864	0.468	0.9979
0.269	0.8869	0.319	0.9322	0.369	0.9650	0.419	0.9868	0.469	0.9981
0.270	0.8880	0.320	0.9330	0.370	0.9656	0.420	0.9871	0.470	0.9982

HEIGHTS AND WIDTHS OF CIRCULAR SEGMENTS.—*Continued*

h	*W*	*h*	*W*	*h*	*W*	*h*	*W*	*h*	*W*
0.271	0.8890	0.321	0.9336	0.371	0.9661	0.421	0.9874	0.471	0.99831
0.272	0.8900	0.322	0.9345	0.372	0.9667	0.422	0.9877	0.472	0.99842
0.273	0.8910	0.323	0.9352	0.373	0.9672	0.423	0.9880	0.473	0.99854
0.274	0.8921	0.324	0.9360	0.374	0.9677	0.424	0.9883	0.474	0.99862
0.275	0.8931	0.325	0.9367	0.375	0.9682	0.425	0.9887	0.475	0.99875
0.276	0.8940	0.326	0.9375	0.376	0.9688	0.426	0.9890	0.476	0.99885
0.277	0.8950	0.327	0.9382	0.377	0.9693	0.427	0.9893	0.477	0.99894
0.278	0.8960	0.328	0.8390	0.378	0.9798	0.428	0.9896	0.478	0.99904
0.279	0.8970	0.329	0.9397	0.379	0.9703	0.429	0.9898	0.479	0.99912
0.280	0.8980	0.330	0.9404	0.380	0.9708	0.430	0.9901	0.480	0.99921
0.281	0.8990	0.331	0.9412	0.381	0.9713	0.431	0.9904	0.481	0.99927
0.282	0.9000	0.332	0.9420	0.382	0.9718	0.432	0.9907	0.482	0.99935
0.283	0.9009	0.333	0.9426	0.383	0.9722	0.433	0.9910	0.483	0.99942
0.284	0.9020	0.334	0.9432	0.384	0.9728	0.434	0.9913	0.484	0.99949
0.285	0.9028	0.335	0.9440	0.385	0.9732	0.435	0.9915	0.485	0.99955
0.286	0.9038	0.336	0.9446	0.386	0.9736	0.436	0.9918	0.486	0.99961
0.287	0.9047	0.337	0.9453	0.387	0.9742	0.437	0.9920	0.487	0.99966
0.288	0.9057	0.338	0.9461	0.388	0.9747	0.438	0.9922	0.488	0.99971
0.289	0.9066	0.339	0.9467	0.389	0.9751	0.439	0.9925	0.489	0.99976
0.290	0.9075	0.340	0.9474	0.390	0.9755	0.440	0.9927	0.490	0.99980
0.291	0.9085	0.341	0.9480	0.391	0.9760	0.441	0.9930	0.491	0.99984
0.292	0.9094	0.342	0.9488	0.392	0.9764	0.442	0.9932	0.492	0.99987
0.293	0.9103	0.343	0.9494	0.393	0.9769	0.443	0.9935	0.493	0.99990
0.294	0.9112	0.344	0.9501	0.394	0.9773	0.444	0.9937	0.494	0.99993
0.295	0.9121	0.345	0.9507	0.395	0.9777	0.445	0.9939	0.495	0.99995
0.296	0.9130	0.346	0.9514	0.396	0.9781	0.446	0.9941	0.496	0.99997
0.297	0.9139	0.347	0.9520	0.397	0.9786	0.447	0.9944	0.497	0.99998
0.298	0.9147	0.348	0.9527	0.398	0.9790	0.448	0.9946	0.498	0.99999
0.299	0.9157	0.349	0.9533	0.399	0.9794	0.449	0.9948	0.499	0.99999
0.300	0.9165	0.350	0.9540	0.400	0.9798	0.450	0.9950	0.500	1.00000

Table for Finding Radius of Segments



Measure width and height of segment to find ratio $\frac{h}{C}$ or $\frac{\text{height}}{\text{Chord}}$. Then find quotient in Col. 1 and opposite in Col. 2 find the Chord C for segment of radius 1. Multiply this by the width of actual segment for the correct radius for that segment. Thus: If the width of chord C is 3 inches and the height 1 inch, then $\frac{1}{3}$ equals 0.333. Find this in column 1 and opposite in column 2 read 0.5419. Multiply by 3, giving 1.6257 inch as the radius required for the segment.

$\frac{h}{C}$	Constant	$\frac{h}{C}$	Constant	$\frac{h}{C}$	Constant	$\frac{h}{C}$	Constant	$\frac{h}{C}$	Constant
0.010	12.500	0.045	2.800	0.080	1.602	0.114	1.1534	0.149	0.9134
0.011	11.362	0.046	2.740	0.081	1.583	0.115	1.1445	0.150	0.9083
0.012	10.418	0.047	2.681	0.082	1.565	0.116	1.1362	0.150	0.9083
0.013	9.611	0.048	2.628	0.083	1.548	0.117	1.1269	0.151	0.9033
0.014	8.846	0.049	2.575	0.084	1.530	0.118	1.1182	0.152	0.8984
0.015	8.341	0.050	2.525	0.085	1.513	0.119	1.1099	0.153	0.8935
0.016	7.821	0.051	2.476	0.086	1.496	0.120	1.1017	0.154	0.8887
0.017	7.361	0.052	2.430	0.087	1.481	0.121	1.0934	0.155	0.8839
0.018	6.838	0.053	3.385	0.088	1.465	0.122	1.0856	0.156	0.8794
0.019	6.581	0.054	2.342	0.089	1.449	0.123	1.1078	0.157	0.8747
0.020	6.260	0.055	2.300	0.090	1.434	0.124	1.0700	0.158	0.8701
0 021	5.962	0.056	2.260	0.091	1.419	0.125	1.1063	0.159	0.8657
0.022	5.693	0.057	2.221	0.092	1.404	0.126	1.0551	0.160	0.8613
0.023	5.446	0.058	2.184	0.093	1.390	0.127	1.0477	0.161	0.8569
0.024	5.231	0.059	2.148	0.094	1.377	0.128	1.0406	0.162	0.8526
0.025	5.012	0.060	2.114	0.095	1.363	0.129	1.0335	0.163	0.8483
0.026	4.812	0.061	2.080	0.096	1.350	0.130	1.0265	0.164	0.8441
0.027	4.643	0.062	2.047	0.097	1.337	0.131	1.0186	0.165	0.8401
0.028	4.478	0.063	2.015	0.098	1.324	0.132	1.0130	0.166	0.8360
0.029	4.325	0.064	1.965	0.099	1.312	0.133	1.0063	0.167	0.8320
0.030	4.181	0.065	1.955	0.100	1.300	0.134	0.9998	0.168	0.8280
0.031	4.048	0.066	1.945			0.135	0.9935	0.169	0.8241
0.032	3.922	0.067	1.899	0.101	1.2871	0.136	0.9871	0.170	0.8203
0.033	3.804	0.068	1.870	0.102	1.2763	0.137	0.9809	0.171	0.8165
0.034	3.693	0.069	1.846	0.103	1.2651	0.138	0.9748	0.172	0.8127
0.035	3.589	0.070	1.821	0.104	1.2539	0.139	0.9688	0.173	0.8091
0.036	3.490	0.071	1.796	0.105	1.2429	0.140	0.9629	0.174	0.8054
0.037	3.400	0.072	1.772	0.106	1.2323	0.141	0.9570	0.175	0.8018
0.038	3.308	0.073	1.749	0.107	1.2217	0.142	0.9513	0.176	0.7983
0.039	3.224	0.074	1.726	0.108	1.2114	0.143	0.9457	0.177	0.7947
0.040	3.130	0.075	1.704	0.109	1.2013	0.144	0.9401	0.178	0.7912
0.041	3.069	0.076	1.683	0.110	1.1903	0.145	0.9345	0.179	0.7877
0.042	2.997	0.077	1.662	0.111	1.1815	0.146	0.9292	0.180	0.7844
0.043	2.928	0.078	1.641	0.112	1.1720	0.147	0.9238	0.181	0.7811
0.044	2.863	0.079	1.602	0.113	1.1628	0.148	0.9185	0.182	0.7778

TABLE FOR FINDING RADIUS OF SEGMENTS.—*Continued*

$\frac{h}{C}$	Constant	$\frac{h}{C}$	Constant	$\frac{h}{C}$	Constant	$\frac{h}{C}$	Constant	$\frac{h}{C}$	Constant
0.183	0.7746	0.232	0.6548	0.282	0.5843	0.332	0.5425	0.382	0.5182
0.184	0.7713	0.233	0.6529	0.283	0.5832	0.333	0.5419	0.383	0.5179
0.185	0.7682	0.234	0.6514	0.284	0.5821	0.334	0.5412	0.384	0.5175
0.186	0.7651	0.235	0.6494	0.285	0.5811	0.335	0.5406	0.385	0.5172
0.187	0.7629	0.236	0.6477	0.286	0.5801	0.336	0.5400	0.386	0.5168
0.188	0.7590	0.237	0.6459	0.287	0.5790	0.337	0.5394	0.387	0.5165
0.189	0.7559	0.238	0.6441	0.288	0.5780	0.338	0.5387	0.388	0.5162
0.190	0.7529	0.239	0.6425	0.289	0.5770	0.339	0.5382	0.389	0.5158
0.191	0.7500	0.240	0.6408	0.290	0.5760	0.340	0.5376	0.390	0.5155
0.192	0.7470	0.241	0.6392	0.291	0.5751	0.341	0.5371	0.391	0.5152
0.193	0.7441	0.242	0.6375	0.292	0.5741	0.342	0.5365	0.392	0.5149
0.194	0.7413	0.243	0.6359	0.293	0.5731	0.343	0.5459	0.393	0.5146
0.195	0.7386	0.244	0.6343	0.294	0.5721	0.344	0.5354	0.394	0.5143
0.196	0.7357	0.245	0.6327	0.295	0.5711	0.345	0.5348	0.395	0.5139
0.197	0.7330	0.246	0.6311	0.296	0.5703	0.346	0.5334	0.396	0.5137
0.198	0.7307	0.247	0.6296	0.297	0.5694	0.347	0.5337	0.397	0.5134
0.199	0.7276	0.248	0.6280	0.298	0.5685	0.348	0.5332	0.398	0.5131
0.200	0.7250	0.249	0.6265	0.299	0.5676	0.349	0.5327	0–399	0–5128
		0.250	0.6250	0.300	0.5666	0.350	0.5321	0.400	0.5125
0.201	0.7224	0.251	0.6235	0.301	0.5658	0.351	0.5316	0.401	0.5122
0.202	0.7199	0.252	0.6220	0.302	0.5649	0.352	0.5311	0.402	0.5119
0.203	0.7173	0.253	0.6205	0.303	0.5641	0.353	0.5306	0.403	0.5117
0.204	0.7147	0.254	0.6290	0.304	0.5632	0.354	0.5302	0.404	0.5114
0.205	0.7123	0.255	0.6177	0.305	0.5623	0.355	0.5296	0.405	0.5111
0.206	0.7098	0.256	0.6163	0.306	0.5615	0.356	0.5291	0.406	0.5109
0.207	0.7074	0.257	0.6150	0.307	0.5607	0.357	0.5287	0.407	0.5106
0.208	0.7050	0.258	0.6135	0.308	0.5599	0.358	0.5282	0.408	0.5104
0.209	0.7026	0.259	0.6122	0.309	0.5590	0.359	0.5277	0.409	0.5101
0.210	0.7003	0.260	0.6108	0.310	0.5582	0.360	0.5272	0.410	0.5099
0.211	0.6978	0.261	0.6094	0.311	0.5575	0.361	0.5268	0.411	0.5096
0.212	0.6957	0.262	0.6081	0.312	0.5566	0.362	0.5263	0.412	0.5094
0.213	0.6933	0.263	0.6066	0.313	0.5558	0.363	0.5258	0.413	0.5092
0.214	0.6911	0.264	0.6054	0.314	0.5551	0.364	0.5254	0.414	0.5089
0.215	0.6889	0.265	0.6042	0.315	0.5543	0.365	0.5249	0.415	0.5087
0.216	0.6867	0.266	0.6029	0.316	0.5536	0.366	0.5245	0.416	0.5085
0.217	0.6845	0.267	0.6016	0.317	0.5528	0.367	0.5241	0.417	0.5082
0.218	0.6820	0.268	0.6004	0.318	0.5521	0.368	0.5237	0.418	0.5080
0.219	0.6803	0.269	0.5992	0.319	0.5513	0.369	0.5233	0.419	0.5078
0.220	0.6782	0.270	0.5980	0.320	0.5506	0.370	0.5228	0.420	0.5076
0.221	0.6761	0.271	0.5968	0.321	0.5509	0.371	0.5224	0.421	0.5074
0.222	0.6740	0.272	0.5955	0.322	0.5492	0.372	0.5220	0.422	0.5072
0.223	0.6720	0.273	0.5944	0.323	0.5485	0.373	0.5216	0.423	0.5070
0.224	0.6700	0.274	0.5933	0.324	0.5478	0.374	0.5212	0.424	0.5068
0.225	0.6680	0.275	0.5920	0.325	0.5471	0.375	0.5208	0.425	0.5066
0.226	0.6660	0.276	0.5909	0.326	0.5463	0.376	0.5205	0.426	0.5064
0.227	0.6641	0.277	0.5898	0.327	0.5457	0.377	0.5201	0.427	0.5062
0.228	0.6623	0.278	0.5886	0.328	0.5451	0.378	0.5197	0.428	0.5061
0.229	0.6603	0.279	0.5875	0.329	0.5444	0.379	0.5192	0.429	0.5059
0.230	0.6585	0.280	0.5864	0.330	0.5438	0.380	0.5189	0.430	0.5057
0.231	0.6566	0.281	0.5853	0.331	0.5431	0.381	0.5186	0.431	0.5055

TABLE FOR FINDING RADIUS OF SEGMENTS.—*Continued*

$\frac{h}{C}$	Constant	$\frac{h}{C}$	Constant	$\frac{h}{C}$	Constant	$\frac{h}{C}$	Constant	$\frac{h}{C}$	Constant
0.432	0.5054	0.447	0.5031	0.461	0.50164	0.476	0.50061	0.491	0.50009
0.433	0.5052	0.448	0.5030	0.462	0.50156	0.477	0.50055	0.492	0.50007
0.434	0.5050	0.449	0.5029	0.463	0.50148	0.478	0.50050	0.493	0.50005
0.435	0.5048	0.450	0.5028	0.464	0.50140	0.479	0.50048	0.494	0.50004
0.436	0.5047	0.450	0.50278	0.465	0.40132	0.480	0.50042	0.495	0.50003
0.437	0.5045	0.451	0.50266	0.466	0.50124	0.481	0.50037	0.496	0.50002
0.438	0.5044	0.452	0.50255	0.467	0.50116	0.482	0.50033	0.497	0.50001
0.439	0.5043	0.453	0.50244	0.468	0.50109	0.483	0.50029	0.498	0.50000
0.440	0.5042	0.454	0.50233	0.469	0.50102	0.484	0.50026	0.499	0.50000
0.441	0.5039	0.455	0.50223	0.470	0.50096	0.485	0.50023	0.500	0.50000
0.442	0.5038	0.456	0.50213	0.471	0.50089	0.486	0.50022		
0.443	0.5037	0.457	0.50203	0.472	0.50083	0.487	0.50021		
0.444	0.5035	0.458	0.50193	0.473	0.50077	0.488	0.50018		
0.445	0.5034	0.459	0.50181	0.474	0.50071	0.489	0.50015		
0.446	0.5033	0.460	0.50174	0.475	0.50066	0.490	0.50012		

GENERAL FACTORS OF SAFETY

Material	Steady Load	Load Varying from Zero to Maximum in One Direction	Load Varying from Zero to Maximum in Both Directions	Suddenly Varying Loads and Shocks
Cast iron	6	10	15	20
Wrought iron	4	6	8	12
Steel	5	6	8	12
Wood	8	10	15	20
Brick	15	20	25	30
Stone	15	20	25	30

TABLE SHOWING SHEARING STRENGTH OF OPEN-HEARTH STEEL PINS
Taken at 7,500 Pounds per Square Inch, Cross Section

Diameter of Pin	Single-Shear Strength, Pounds	Diameter of Pin	Single-Shear Strength, Pounds
$\frac{3}{8}$	828	$1\frac{3}{4}$	18,037
$\frac{1}{2}$	1,472	$1\frac{7}{8}$	20,707
$\frac{5}{8}$	2,301	2"	23,565
$\frac{3}{4}$	3,313	$2\frac{1}{8}$	26,600
$\frac{7}{8}$	4,510	$2\frac{1}{4}$	29,820
1"	5,890	$2\frac{3}{8}$	33,225
$1\frac{1}{8}$	7,455	$2\frac{1}{2}$	36,817
$1\frac{1}{4}$	9,202	$2\frac{5}{8}$	40,590
$1\frac{3}{8}$	11,132	$2\frac{3}{4}$	44,550
$1\frac{1}{2}$	13,252	$2\frac{7}{8}$	48,690
$1\frac{5}{8}$	15,555	3"	53,010

Foote Brothers.

SECTION XIX

WIRE GAGES AND STOCK WEIGHTS

Twist Drill and Steel Wire Gage Sizes

THE Twist Drill and Steel Wire Gage is used for measuring the sizes of twist drills and steel drill rods. Rod sizes by this gage should not be confused with Stubs' Steel Wire Gage sizes. The difference between the sizes of corresponding numbers in the two gages ranges from about .0005 to .004 inch, the Stubs sizes being the smaller except in the cases of a few numbers where the systems coincide exactly.

TWIST DRILL AND STEEL WIRE GAGE SIZES

No. of Gage	Dia. in Inches	No. of Gage	Dia. in Inches	No. of Gage	Dia. in Inches	No. of Gage	Dia. in Inches
1	.2280	21	.1590	41	.0960	61	.0390
2	.2210	22	.1570	42	.0935	62	.0380
3	.2130	23	.1540	43	.0890	63	.0370
4	.2090	24	.1520	44	.0860	64	.0360
5	.2055	25	.1495	45	.0820	65	.0350
6	.2040	26	.1470	46	.0810	66	.0330
7	.2010	27	.1440	47	.0785	67	.0320
8	.1990	28	.1405	48	.0760	68	.0310
9	.1960	29	.1360	49	.0730	69	.02925
10	.1935	30	.1285	50	.0700	70	.0280
11	.1910	31	.1200	51	.0670	71	.0260
12	.1890	32	.1160	52	.0635	72	.0250
13	.1850	33	.1130	53	.0595	73	.0240
14	.1820	34	.1110	54	.0550	74	.0225
15	.1800	35	.1100	55	.0520	75	.0210
16	.1770	36	.1065	56	.0465	76	.0200
17	.1730	37	.1040	57	.0430	77	.0180
18	.1695	38	.1015	58	.0420	78	.0160
19	.1660	39	.0995	59	.0410	79	.0145
20	.1610	40	.0980	60	.0400	80	.0135

STUBS' GAGES

IN using Stubs' Gages, the difference between the Stubs Iron Wire Gage and the Stubs Steel Wire Gage should be kept in mind. The Stubs Iron Wire Gage is the one commonly known as the English Standard Wire, or Birmingham Gage, and designates the Stubs soft wire sizes. The Stubs Steel Wire Gage is used in measuring drawn steel wire or drill rods of Stubs' make and is also used by many American makers of drill rods.

DIMENSIONS IN DECIMAL PARTS OF AN INCH

Number of Gage	American or Brown & Sharpe	Birmingham or Stubs' Iron Wire	Washburn & Moen Mfg. Co.	Trenton Iron Co.	Stubs' Steel Wire	Imperial Wire Gage	Old Standard for Plate
000000	....	......	......	......	......	.464	.460
00000	....	......	......	.450	......	.432	.429
0000	.46	.454	.3938	.400	......	.400	.398
000	.40964	.425	.3625	.360	......	.372	.368
00	.3648	.380	.3310	.330	......	.348	.337
0	.32486	.340	.3065	.305	......	.324	.306
1	.2893	.300	.2830	.285	.227	.300	.2757
2	.25763	.284	.2625	.265	.219	.276	.2604
3	.22942	.259	.2437	.245	.212	.252	.2451
4	.20431	.238	.2253	.225	.207	.232	.2298
5	.18194	.220	.2070	.205	.204	.212	.2145
6	.16202	.203	.1920	.190	.201	.192	.1991
7	.14428	.180	.1770	.175	.199	.176	.1838
8	.12849	.165	.1620	.160	.197	.160	.1685
9	.11443	.148	.1483	.145	.194	.144	.1532
10	.10189	.134	.1350	.130	.191	.128	.1379
11	.090742	.120	.1205	.1175	.188	.116	.1225
12	.080808	.109	.1055	.105	.185	.104	.1072
13	.071961	.095	.0915	.0925	.182	.092	.0919
14	.064084	.083	.0800	.080	.180	.080	.0766
15	.057068	.072	.0720	.070	.178	.072	.0689
16	.05082	.065	.0625	.061	.175	.064	.0613
17	.045257	.058	0540	.0525	.172	.056	.0551
18	.040303	.049	.0475	.045	.168	.048	.0490
19	.03589	.042	.0410	.040	.164	.040	.0429
20	.031961	.035	.0348	.035	.161	.036	.0368
21	.028462	.032	.03175	.031	.157	.032	.0337
22	.025347	.028	.0286	.028	.155	.028	.0306
23	.022571	.025	.0258	.025	.153	.024	.0276
24	.0201	.022	.0230	.0225	.151	.022	.0245
25	.0179	.020	.0204	.020	.148	.020	.0214
26	.01594	.018	.0181	.018	.146	.018	.0184
27	.014195	.016	.0173	.017	.143	.0164	.0169
28	.012641	.014	.0162	.016	.139	.0149	.0153
29	.011257	.013	.0150	.015	.134	.0136	.0138
30	.010025	.012	.0140	.014	.127	.0124	.0123
31	.008928	.010	.0132	.013	.120	.0116	.0107
32	.00795	.009	.0128	.012	.115	.0108	.0100
33	.00708	.008	.0118	.011	.112	.0100	.0092
34	.006304	.007	.0104	.010	.110	.0092	.0084
35	.005614	.005	.0095	.0095	.108	.0084	.0077
36	.005	.004	.0090	.009	.106	.0076	.0069
37	.004453			.0085	.103	.0068	.0065
38	.003965			.008	.101	.0060	.0061
39	.003531			.0075	.099	.0052	.0057
40	.003144			.007	.097	.0048	0054

WIRE AND DRILL SIZES ARRANGED CONSECUTIVELY

Dia. of Wire	American or B. & S.	B'ham or Stubs' Wire	Stubs' Steel Wire	Twist Drill and Steel Wire	Dia. of Wire	American or B. & S.	B'ham or Stubs' Wire	Stubs' Steel Wire	Twist Drill or Steel Wire
	Gage Number					Gage Number			
.00314	40				.041			58	59
.00353	39				.042		19	57	58
.00397	38				.043				57
.004		36			.045			56	
.0045	37				.0453	17			
.005	36	35			.0465				56
.0056	35				.049		18		
.0063	34				.050			55	
.007		34			.0508	16			
.0071	33				.052				55
.008	32	33			.055			54	54
.0089	31				.0571	15			
.009		32			.058		17	53	
.010	30	31			.0595				53
.0113	29				.063			52	
.012		30			.0635				52
.0126	28				.0641	14			
.013		29	80		.065		16		
.0135				80	.066			51	
.014		28	79		.067				51
.0142	27				.069			50	
.0145				79	.070				50
.015			78		.072	13	15	49	
.0159	26				.073				49
.016		27	77	78	.075			48	
.0179	25				.076				48
.018		26	76	77	.077			47	
.020		25	75	76	.0785				47
.0201	24				.079			46	
.021				75	.0808	12			
.022		24	74		.081			45	46
.0225				74	.082				45
.0226	23				.083		14		
.023			73		.085			44	
.024			72	73	.086				44
.025		23		72	.088			43	
.0253	22				.089				43
.026			71	71	.0907	11			
.027			70		.092			42	
.028		22		70	.0935				42
.0285	21				.095		13	41	
.029			69		.096				41
.0293				69	.097			40	
.030			68		.098				40
.031			67	68	.099			39	
.032	20	21	66	67	.0995				39
.033			65	66	.101			38	
.035		20	64	65	.1015				38
.0359	19				.1019	10			
.036			63	64	.103			37	
.037			62	63	.104				37
.038			61	62	.106			36	
.039			60	61	.1065				36
.040			59	60	.108			35	
.0403	18								

WIRE AND DRILL SIZES ARRANGED CONSECUTIVELY

Dia. of Wire	American or B. & S.	B'ham or Stubs' Wire	Stubs' Steel Wire	Twist Drill and Steel Wire	Dia. of Wire	American or B. & S.	B'ham or Stubs' Wire	Stubs' Steel Wire	Twist Drill and Steel Wire
	Gage Number					Gage Number			
.109		12			.203		6		
.110			34	35	.204			5	6
.111				34	.2043	4			
.112			33		.2055				5
.113				33	.207			4	
.1144	9				.209				4
.115			32		.212			3	
.116				32	.213				3
.120		11	31	31	.219			2	
.127			30		.220		5		
.1285	8			30	.221				2
.134		10	29		.227			1	
.136				29	.228				1
.139			28		.2294	3			
.1405				28	.234			A	
.143			27		.238		4	B	
.144				27	.242			C	
.1443	7				.246			D	
.146			26		.250			E	
.147				26	.257			F	
.148		9	25		.2576	2			
.1495				25	.259		3		
.151			24		.261			G	
.152				24	.266			H	
.153			23		.272			I	
.154				23	.277			J	
.155			22		.281			K	
.157			21	22	.284		2		
.159				21	.2893	1			
.161			20	20	.290			L	
.162	6				.295			M	
.164			19		.300		1		
.165		8			.302			N	
.166				19	.316			O	
.168			18		.323			P	
.1695				18	.3249	0			
.172			17		.332			Q	
.173				17	.339			R	
.175			16		.340		0		
.177				16	.348			S	
.178			15		.358			T	
.180		7	14	15	.3648	00			
.1819	5				.368			U	
.182			13	14	.377			V	
.185			12	13	.380		00		
.188			11		.386			W	
.189				12	.397			X	
.191			10	11	.404			Y	
.1935				10	.4096	000			
.194			9		.413			Z	
.196				9	.425		000		
.197			8		.454		0000		
.199			7	8	.460	0000			
.201			6	7					

STUBS' STEEL WIRE SIZES AND WEIGHTS

As stated in the explanatory note regarding Stubs' Gages at the bottom of page 940 the Stubs steel wire gage is used for measuring drawn steel wire and drill rods of Stubs' make and is also used by various drill rod makers in America.

STUBS' STEEL WIRE SIZES, AND WEIGHT IN POUNDS PER LINEAR FOOT

Letter and No. of Gage	Dia. in Inches	Weight per Foot	No. of Wire Gage	Dia. in Inches	Weight per Foot	No. of Wire Gage	Dia. in Inches	Weight per Foot
Z	.413	.456	10	.191	.098	46	.079	.017
Y	.404	.437	11	.188	.095	47	.077	.016
X	.397	.422	12	.185	.092	48	.075	.015
W	.386	.399	13	.182	.089	49	.072	.014
V	.377	.380	14	.180	.087	50	.069	.013
U	.368	.362	15	.178	.085	51	.066	.012
T	.358	.335	16	.175	.082	52	.063	.011
S	.348	.324	17	.172	.079	53	.058	.009
R	.339	.307	18	.168	.075	54	.055	.008
Q	.332	.295	19	.164	.072	55	.050	.007
P	.323	.280	20	.161	.069	56	.045	.006
O	.316	.267	21	.157	.066	57	.042	.0047
N	.302	.244	22	.155	.064	58	.041	.0045
M	.295	233	23	.153	.063	59	.040	.0042
L	.290	.225	24	.151	.061	60	.039	.0040
K	.281	.211	25	.148	.059	61	.038	.0039
J	.277	.205	26	.146	.057	62	.037	.0037
I	.272	.192	27	.143	.055	63	.036	.0035
H	.266	.189	28	.139	.052	64	.035	.0033
G	.261	.182	29	.134	.048	65	.033	.0029
F	.257	.177	30	.127	.043	66	.032	.0027
E	.250	.167	31	.120	.039	67	.031	.0026
D	.246	.162	32	.115	.035	68	.030	.0024
C	.242	.159	33	.112	.034	69	.029	.0022
B	.238	.152	34	.110	.032	70	.027	.0020
A	.234	.146	35	.108	.031	71	.026	.0018
1	.227	.138	36	.106	.030	72	.024	.0015
2	.219	.128	37	.103	.028	73	.023	.0014
3	.212	.120	38	.101	.027	74	.022	.0013
4	.207	.115	39	.099	.026	75	.020	.0011
5	.204	.111	40	.097	.025	76	.018	.0009
6	.201	.108	41	.095	.024	77	.016	.0007
7	.199	.106	42	.092	.023	78	.015	.0006
8	.197	.104	43	.088	.020	79	.014	.0005
9	.194	.101	44	.085	.019	80	.013	.0004
			45	.081	.018			

MUSIC WIRE SIZES

No. of Gage	Diameter	No. of Gage	Diameter	No. of Gage	Diameter	No. of Gage	Diameter
6–0	0.004	8	0.020	21	0.047	34	0.100
5–0	0.005	9	0.022	22	0.049	35	0.106
4–0	0.006	10	0.024	23	0.051	36	0.112
3–0	0.007	11	0.026	24	0.055	37	0.118
2–0	0.008	12	0.029	25	0.059	38	0.124
0	0.009	13	0.031	26	0.063	39	0.130
1	0.010	14	0.033	27	0.067	40	0.138
2	0.011	15	0.035	28	0.071	41	0.146
3	0.012	16	0.037	29	0.075	42	0.154
4	0.013	17	0.039	30	0.080	43	0.162
5	0.014	18	0.041	31	0.085	44	0.170
6	0.016	19	0.043	32	0.090	45	0.180
7	0.018	20	0.045	33	0.095		

Due to the fact that the wire gage of the American Steel Wire Company was most extensively used this gage has been recommended by the Bureau of Standards. On this account it has seemed best to publish only these sizes, as given above.

WEIGHT AND APPROXIMATE THICKNESS OF SHEET STEEL

U. S. Standard Gage

The U. S. gage is a weight and not a thickness gage, being based on wrought iron at 0.2778 pounds per cubic inch or 480 pounds per cubic foot. The numbers, or gage thicknesses, were to give definite weight per square foot, No. 0000000 being 0.5 inch and wrought iron of this gage weighing 20 pounds per square foot.

Because steel has almost entirely superseded wrought iron for sheet use since the U. S. gage was established, the density of rolled steel, 0.2833 pound per cubic inch, or 489.6 pounds per cubic foot was adopted by the Association of American Steel Manufacturers, the A. S. T. M., and approved by the Bureau of Standards. The Manufacturers' Standard Gage now uses 41.82 pounds per square foot for steels 1 inch thick. This gives the table on page 946, dated August, 1940.

Sheets up to and including No. 5, or 0.2145 in. are called "sheets" —above this they are called "plates."

For commercial tolerances see pages 960 to 967.

MANUFACTURERS' STANDARD GAGE FOR SHEET STEEL

Gage-thickness equivalents are based on 0.0014945 inch per ounce per square foot; 0.023912 inch per pound per square foot (reciprocal of 41.82 lb. per square foot per inch thick); 3.443329 inches per pound per square inch.

Manufacturers' Standard Gage No.	Ounces per Square Foot	Pounds per Square Inch	Pounds per Square Foot	Inch Equivalent for Steel Sheet Thickness	Manufacturers' Standard Gage No.
3	160	0.069444	10.0000	0.2391	3
4	150	0.065104	9.3750	0.2242	4
5	140	0.060764	8.7500	0.2092	5
6	130	0.056424	8.1250	0.1943	6
7	120	0.052083	7.5000	0.1793	7
8	110	0.047743	6.8750	0.1644	8
9	100	0.043403	6.2500	0.1495	9
10	90	0.039062	5.6250	0.1345	10
11	80	0.034722	5.0000	0.1196	11
12	70	0.030382	4.3750	0.1046	12
13	60	0.026042	3.7500	0.0897	13
14	50	0.021701	3.1250	0.0747	14
15	45	0.019531	2.8125	0.0673	15
16	40	0.017361	2.5000	0.0598	16
17	36	0.015625	2.2500	0.0538	17
18	32	0.013889	2.0000	0.0478	18
19	28	0.012153	1.7500	0.0418	19
20	24	0.010417	1.5000	0.0359	20
21	22	0.0095486	1.3750	0.0329	21
22	20	0.0086806	1.2500	0.0299	22
23	18	0.0078125	1.1250	0.0269	23
24	16	0.0069444	1.0000	0.0239	24
25	14	0.0060764	0.8750	0.0209	25
26	12	0.0052083	0.7500	0.0179	26
27	11	0.0047743	0.6875	0.0164	27
28	10	0.0043403	0.6250	0.0149	28
29	9	0.0039062	0.5625	0.0135	29
30	8	0.0034722	0.5000	0.0120	30
31	7	0.0030382	0.43750	0.0105	31
32	6.5	0.0028212	0.40625	0.0097	32
33	6	0.0026042	0.37500	0.0090	33
34	5.5	0.0023872	0.34375	0.0082	34
35	5	0.0021701	0.31250	0.0075	35
36	4.5	0.0019531	0.28125	0.0067	36
37	4.25	0.0018446	0.26562	0.0064	37
38	4	0.0017361	0.25000	0.0060	38

Weights of Aluminum, Brass and Copper Plates
American or Brown & Sharpe Gage

No. of Gage	Thickness in Inches	Weight in Lbs. per Square Foot		
		Aluminum	Brass	Copper
0000	.46	6.48	19 688	20.838
000	.4096	5.77	17.533	18.557
00	.3648	5.14	15.613	16.525
0	.3249	4.58	13.904	14.716
1	.2893	4.08	12.382	13.105
2	.2576	3.63	11.027	11.670
3	.2294	3.23	9.819	10.392
4	.2043	2.88	8.745	9.255
5	.1819	2.56	7.788	8.242
6	.1620	2.28	6.935	7.340
7	.1443	2.03	6.175	6.536
8	.1285	1.81	5.499	5.821
9	.1144	1.61	4.898	5.183
10	.1019	1.44	4.631	4.616
11	.0908	1.28	3.884	4.110
12	.0808	1.14	3.458	3.660
13	.0720	1.01	3.080	3.260
14	.0641	.903	2.743	2.903
15	.0571	.804	2.442	2.585
16	.0508	.716	2 175	2.302
17	.0453	.638	1.937	2.050
18	.0403	.568	1.725	1.825
19	.0359	.506	1.536	1.626
20	.0320	.450	1.367	1.448
21	.0285	.401	1.218	1.289
22	.0253	.357	1.085	1.148
23	.0226	.318	.966	1.023
24	.0201	.283	.860	.910
25	.0179	.252	.766	.811
26	.0159	.225	.682	.722
27	.0142	.200	.608	.643
28	.0126	.178	.541	.573
29	.0113	.159	.482	.510
30	.0100	.141	.429	.454
31	.0089	.126	.382	.404
32	.0080	.113	.340	.360
33	.0071	.100	.303	.321
34	.0063	.0888	.269	.286
35	.0056	.0790	.240	.254
36	.0050	.0704	.214	.226
37	.0045	.0627	.191	.202
38	.0040	.0558	.170	.180
39	.0035	.0497	.151	.160
40	.0031	.0442	.135	.142

Sheet-Metal Weights per Square Inch

The draftsman, or toolmaker at times, has occasion to calculate the weights of certain small parts made from sheet stock, particularly in connection with press work; and it is convenient often to be able to find directly the weight of materials per square inch instead of having to take the square-foot weight, as commonly given in tables, and then divide by 144 or, better yet, multiply by 0.007.

For this reason the table here, which is compiled for aluminum, brass, and copper in American or Brown and Sharpe gage and for brass and copper in Birmingham or Stubs' gage, may be of service.

This is especially of interest where small, light parts have to be figured for weight to determine their operation in relation to other parts, that is, where weight and area may have to be adjusted in respect to each other. This would apply among other parts to certain types of small floating members, liquid control diaphragms, and the like.

WEIGHT PER SQUARE INCH FOR ALUMINUM, BRASS, AND COPPER

American or Brown and Sharpe Gage					Birmingham or Stubs' Gage		
No. Gage	Thickness in Inches	Aluminum	Brass	Copper	Thickness in Inches	Brass	Copper
0000	0.46	0.045	0.137	0.145	0.454	0.135	0.143
000	0.4086	0.040	0.123	0.129	0.425	0.127	0.134
00	0.3648	0.036	0.109	0.115	0.380	0.114	0.120
0	0.3249	0.033	0.0973	0.130	0.340	0.101	0.102
1	0.2893	0.028	0.0866	0.091	0.300	0.089	0.095
2	0.2576	0.025	0.0771	0.083	0.284	0.085	0.091
3	0.2294	0.023	0.068	0.072	0.259	0.077	0.079
4	0.2043	0.020	0.061	0.064	0.238	0.071	0.075
5	0.1819	0.018	0.054	0.057	0.220	0.065	0.070
6	0.1620	0.016	0.048	0.051	0.203	0.0608	0.064
7	0.1443	0.014	0.043	0.045	0.180	0.0538	0.057
8	0.1285	0.013	0.040	0.042	0.165	0.049	0.052
9	0.1144	0.0127	0.034	0.036	0.148	0.044	0.046
10	0.1019	0.010	0.032	0.033	0.134	0.040	0.042
11	0.0908	0.009	0.027	0.028	0.120	0.036	0.038
12	0.080	0.008	0.024	0.025	0.109	0.032	0.034
13	0.0720	0.007	0.0215	0.022	0.095	0.028	0.030
14	0.0641	0.006	0.019	0.0205	0.085	0.024	0.0263
15	0.0571	0.0056	0.017	0.018	0.072	0.021	0.0228
16	0.0508	0.005	0.015	0.016	0.065	0.019	0.020
17	0.0453	0.0044	0.0135	0.0143	0.058	0.017	0.018
18	0.0403	0.004	0.012	0.0127	0.049	0.014	0.015
19	0.0359	0.0037	0.0107	0.0113	0.042	0.0125	0.0133
20	0.0320	0.0031	0.0096	0.0104	0.035	0.0104	0.0110
21	0.0285	0.0028	0.0085	0.009	0.032	0.0095	0.0101
22	0.0253	0.0025	0.0076	0.0080	0.028	0.0083	0.009
23	0.0226	0.0022	0.0067	0.0071	0.025	0.0074	0.0079
24	0.0201	0.002	0.006	0.0063	0.022	0.0065	0.0070
25	0.0179	0.0017	0.0053	0.0056	0.020	0.0059	0.0063
26	0.0159	0.0016	0.0047	0.0050	0.018	0.0053	0.0057
27	0.0142	0.0014	0.0043	0.0045	0.016	0.0047	0.0050
28	0.0126	0.0012	0.0037	0.0041	0.014	0.0041	0.0044
29	0.0113	0.0011	0.0033	0.0035	0.013	0.0038	0.0041
30	0.0100	0.0010	0.0030	0.0031	0.012	0.0035	0.0038
31	0.0089	0.0009	0.0027	0.0028	0.010	0.0029	0.0031
32	0.0080	0.0008	0.0023	0.0025	0.009	0.0026	0.0028
33	0.0071	0.0007	0.0021	0.0022	0.008	0.0023	0.0025
34	0.0063	0.0006	0.0018	0.0020	0.007	0.0020	0.0022
35	0.0056	0.00055	0.0016	0.0017	0.005	0.0014	0.0015
36	0.0050	0.0005	0.0014	0.0015	0.004	0.0011	0.0012
37	0.0045	0.00043	0.0013	0.0014			
38	0.0040	0.00039	0.0011	0.0012			
39	0.0035	0.00034	0.0010	0.0011			
40	0.0031	0.0003	0.0009	0.0010			

WEIGHTS OF STEEL, WROUGHT IRON, BRASS AND COPPER PLATES

BIRMINGHAM OR STUBS' GAGE

No. of Gage	Thickness in Inches	Weight in Lbs. per Square Foot			
		Steel	Iron	Brass	Copper
0000	.454	18.52	18.16	19.431	20.556
000	.425	17.34	17.00	18.190	19.253
00	.380	15.30	15.20	16.264	17.214
0	.340	13.87	13.60	14.552	15.402
1	.300	12.24	12.00	12.840	13.590
2	.284	11.59	11.36	12.155	12.865
3	.259	10.57	10.36	11.085	11.733
4	.238	9.71	9.52	10.186	10.781
5	.220	8.98	8.80	9.416	9.966
6	.203	8.28	8.12	8.689	9.196
7	.180	7.34	7.20	7.704	8.154
8	.165	6.73	6.60	7.062	7.475
9	.148	6.04	5.92	6.334	6.704
10	.134	5.47	5.36	5.735	6.070
11	.120	4.90	4.80	5.137	5.436
12	.109	4.45	4.36	4.667	4.938
13	.095	3.88	3.80	4.066	4.303
14	.083	3.39	3.32	3.552	3.769
15	.072	2.94	2.88	3.081	3.262
16	.065	2.65	2.60	2.782	2.945
17	.058	2.37	2.32	2.482	2.627
18	.049	2.00	1.96	2.097	2.220
19	.042	1.71	1.68	1.797	1.902
20	.035	1.43	1.40	1.498	1.585
21	.032	1.31	1.28	1.369	1.450
22	.028	1.14	1.12	1.198	1.270
23	.025	1.02	1.00	1.070	1.132
24	.022	.898	.88	.941	.997
25	.020	.816	.80	.856	.906
26	.018	.734	.72	.770	.815
27	.016	.653	.64	.685	.725
28	.014	.571	.56	.599	.634
29	.013	.530	.52	.556	.589
30	.012	.490	.48	.514	.544
31	.010	.408	.40	.428	.453
32	.009	.367	.36	.385	.408
33	.008	.326	.32	.342	.362
34	.007	.286	.28	.2996	.317
35	.005	.204	.20	.214	.227
36	.004	.163	.16	.171	.181

WEIGHTS OF STEEL, IRON, BRASS AND COPPER WIRE
AMERICAN OR BROWN & SHARPE GAGE

No. of Gage	Dia. in Inches	Weight in Lbs. per 1000 Linear Feet			
		Steel	Iron	Brass	Copper
0000	.4600	566.03	560.74	605.18	640.51
000	.4096	448.88	444.68	479.91	507.95
00	.3648	355.99	352.66	380.67	402.83
0	.3247	282.30	279.67	301.82	319.45
1	.2893	223.89	221.79	239.35	253.34
2	.2576	177.55	175.89	189.82	200.91
3	.2294	140.80	139.48	150.52	159.32
4	.2043	111.66	110.62	119.38	126.35
5	.1819	88.548	87.720	94.666	100.20
6	.1620	70.221	69.565	75.075	79.462
7	.1443	55.685	55.165	59.545	63.013
8	.1285	44.164	43.751	47.219	49.976
9	.1144	35.026	34.699	37.437	39.636
10	.1019	27.772	27.512	29.687	31.426
11	.0907	22.026	21.820	23.549	24.924
12	.0808	17.468	17.304	18.676	19.766
13	.0720	13.851	13.722	14.809	15.674
14	.0641	10.989	10.886	11.746	12.435
15	.0571	8.712	8.631	9.315	9.859
16	.0508	6.909	6.845	7.587	7.819
17	.0453	5.478	5.427	5.857	6.199
18	.0403	4.344	4.304	4.645	4.916
19	.0359	3.445	3.413	3.684	3.899
20	.0320	2.734	2.708	2.920	3.094
21	.0285	2.167	2.147	2.317	2.452
22	.0253	1.719	1.703	1.838	1.945
23	.0226	1.363	1.350	1.457	1.542
24	.0201	1.081	1.071	1.155	1.223
25	.0179	.8571	.8491	.9163	.9699
26	.0159	.6797	.6734	.7267	.7692
27	.0142	.5391	.5340	.5763	.6099
28	.0126	.4275	.4235	.4570	.4837
29	.0113	.3389	.3358	.3624	.3835
30	.0100	.2688	.2663	.2874	.3042
31	.0089	.2132	.2113	.2280	.2413
32	.0080	.1691	.1675	.1808	.1913
33	.0071	.1341	.1328	.1434	.1517
34	.0063	.1063	.1053	.1137	.1204
35	.0056	.0844	.0836	.0901	.0956
36	.0050	.0668	.0662	.0715	.0757
37	.0045	.0530	.0525	.0567	.0600
38	.0040	.0420	.0416	.0449	.0475
39	.0035	.0333	.0330	.0356	.0375
40	.0031	.0264	.0262	.0282	.0299

WEIGHT PER INCH OF ROUND BARS OF CARBON AND HIGH-SPEED STEEL IN POUNDS PER LINEAR INCH

Diameter of Bar, in Inches	Weight of Bar 1 Inch Long		Diameter of Bar, in Inches	Weight of Bar 1 Inch Long		Diameter of Bar, in Inches	Weight of Bar 1 Inch Long	
	Carbon Steel	High-speed Steel		Carbon Steel	High-speed Steel		Carbon Steel	High-speed Steel
1/16	0.00087	0.00098	2 7/16	1.33	1.496	4 13/16	5.15	5.793
1/8	0.0035	0.0039	2 1/2	1.39	1.563	4 7/8	5.28	5.940
3/16	0.0078	0.0088	2 9/16	1.46	1.642	4 15/16	5.42	6.097
1/4	0.0139	0.0156	2 5/8	1.53	1.721	5	5.56	6.255
5/16	0.0217	0.0244	2 11/16	1.61	1.811	5 1/16	5.70	6.412
3/8	0.0313	0.0352	2 3/4	1.68	1.890	5 1/8	5.84	6.570
7/16	0.0425	0.0478	2 13/16	1.76	1.980	5 3/16	5.98	6.727
1/2	0.0556	0.0625	2 7/8	1.84	2.070	5 1/4	6.13	6.896
9/16	0.0703	0.0791	2 15/16	1.92	2.160	5 5/16	6.27	7.053
5/8	0.0868	0.0976	3	2.00	2.250	5 3/8	6.42	7.222
11/16	0.105	0.118	3 1/16	2.08	2.340	5 7/16	6.57	7.391
3/4	0.125	0.141	3 1/8	2.17	2.441	5 1/2	6.72	7.560
13/16	0.147	0.165	3 3/16	2.26	2.542	5 9/16	6.88	7.740
7/8	0.170	0.191	3 1/4	2.35	2.643	5 5/8	7.03	7.908
15/16	0.195	0.219	3 5/16	2.44	2.745	5 11/16	7.19	8.088
1	0.22	0.248	3 3/8	2.53	2.846	5 3/4	7.35	8.268
1 1/16	0.25	0.281	3 7/16	2.63	2.958	5 13/16	7.51	8.448
1 1/8	0.28	0.315	3 1/2	2.72	3.060	5 7/8	7.67	8.628
1 3/16	0.31	0.349	3 9/16	2.82	3.172	5 15/16	7.84	8.820
1 1/4	0.35	0.397	3 5/8	2.92	3.285	6	8.00	9.000
1 5/16	0.38	0.427	3 11/16	3.02	3.397	6 1/8	8.34	9.382
1 3/8	0.42	0.472	3 3/4	3.13	3.521	6 1/4	8.68	9.765
1 7/16	0.46	0.517	3 13/16	3.23	3.633	6 3/8	9.03	10.16
1 1/2	0.50	0.562	3 7/8	3.34	3.757	6 1/2	9.39	10.56
1 9/16	0.54	0.607	3 15/16	3.45	3.881	6 5/8	9.76	10.98
1 5/8	0.59	0.663	4	3.56	4.005	6 3/4	10.1	11.36
1 11/16	0.63	0.709	4 1/16	3.67	4.128	6 7/8	10.5	11.81
1 3/4	0.68	0.765	4 1/8	3.78	4.252	7	10.9	12.26
1 13/16	0.73	0.821	4 3/16	3.90	4.387	7 1/8	11.3	12.71
1 7/8	0.78	0.877	4 1/4	4.01	4.511	7 1/4	11.7	13.16
1 15/16	0.83	0.933	4 5/16	4.13	4.646	7 3/8	12.1	13.61
2	0.89	1.001	4 3/8	4.25	4.781	7 1/2	12.5	14.06
2 1/16	0.94	1.057	4 7/16	4.38	4.927	7 5/8	12.9	14.51
2 1/8	1.00	1.125	4 1/2	4.50	5.062	7 3/4	13.3	14.96
2 3/16	1.06	1.192	4 9/16	4.63	5.208	7 7/8	13.8	15.52
2 1/4	1.13	1.271	4 5/8	4.75	5.343	8	14.3	16.08
2 5/16	1.19	1.338	4 11/16	4.88	5.490			
2 3/8	1.25	1.406	4 3/4	5.01	5.636			

Weights of Iron, Brass, and Copper Wire
BIRMINGHAM OR STUBS' GAGE

No. of Gage	Dia. in Inches	Weight in Lbs. per 1000 Linear Feet		
		Iron	Brass	Copper
0000	.454	546.21	589.29	623.2
000	.425	478.65	516.41	546.1
00	.380	382.66	412.84	436.6
0	.340	306.34	330.50	349.5
1	.300	238.50	257.31	272.1
2	.284	213.74	230.60	243.9
3	.259	177.77	191.79	202.8
4	.238	150.11	161.95	171.3
5	.220	128.26	138.37	146.3
6	.203	109.20	117.82	124.6
7	.180	85.86	92.63	97.96
8	.165	72.14	77.83	82.31
9	.148	58.05	62.62	66.23
10	.134	47.58	51.34	54.29
11	.120	38.16	41.17	43.54
12	.109	31.49	33.97	35.92
13	.095	23.92	25.80	27.29
14	.083	18.26	19.70	20.83
15	.072	13.73	14.82	15.67
16	.065	11.19	12.08	12.77
17	.058	8.92	9.62	10.17
18	.049	6.36	6.86	7.259
19	.042	4.67	5.04	5.333
20	.035	3.25	3.52	3.704
21	.032	2.71	2.93	3.096
22	.028	2.08	2.24	2.370
23	.025	1.66	1.79	1.890
24	.022	1.28	1.39	1.463
25	.020	1.06	1.14	1.209
26	.018	.863	.926	.979
27	.016	.680	.732	.774
28	.014	.529	.560	592
29	.013	.438	.483	.511
30	.012	.382	.412	.435
31	.010	.266	.286	.302
32	.009	.212	.232	.244
33	.008	.167	.183	.193
34	.007	.133	.140	.148
35	.005	.066	.071	.075
36	.004	.046	.048	.052

WEIGHTS OF STEEL AND IRON BARS PER LINEAR FOOT

Dia. or Distance Across Flats	STEEL				IRON	
	Weight per Foot				Weight per Foot	
	Round	Square	Hexagon	Octagon	Round	Square
1/16	.010	.013	.012	.011	.010	.013
1/8	.042	.053	.046	.044	.041	.052
3/16	.094	.119	.103	.099	.092	.117
1/4	.167	.212	.185	.177	.164	.208
5/16	.261	.333	.288	.277	.256	.326
3/8	.375	.478	.414	.398	.368	.469
7/16	.511	.651	.564	.542	.501	.638
1/2	.667	.850	.737	.708	.654	.833
9/16	.845	1.076	.932	.896	.828	1.055
5/8	1.043	1.328	1.151	1.107	1.023	1.302
11/16	1.262	1.608	1.393	1.331	1.237	1.576
3/4	1.502	1.913	1.658	1.584	1.473	1.875
13/16	1.763	2.245	1.944	1.860	1.728	2.201
7/8	2.044	2.603	2.256	2.156	2.004	2.552
15/16	2.347	2.989	2.591	2.482	2.301	2.930
1	2.670	3.400	2.947	2.817	2.618	3.333
1 1/16	3.014	3.838	3.327	3.182	2.955	3.763
1 1/8	3.379	4.303	3.730	3.568	3.313	4.219
1 3/16	3.766	4.795	4.156	3.977	3.692	4.701
1 1/4	4.173	5.312	4.605	4.407	4.091	5.208
1 5/16	4.600	5.857	5.077	4.858	4.510	5.742
1 3/8	5.049	6.428	5.571	5.331	4.950	6.302
1 7/16	5.518	7.026	6.091	5.827	5.410	6.888
1 1/2	6.008	7.650	6.631	6.344	5.890	7.500
1 9/16	6.520	8.301	7.195	6.905	6.392	8.138
1 5/8	7.051	8.978	7.776	7.446	6.913	8.802
1 11/16	7.604	9.682	8.392	8.027	7.455	9.492
1 3/4	8.178	10.41	9.025	8.635	8.018	10.21
1 13/16	8.773	11.17	9.682	9.264	8.601	10.95
1 7/8	9.388	11.95	10.36	9.918	9.204	11.72
1 15/16	10.02	12.76	11.06	10.58	9.828	12.51
2	10.68	13.60	11.79	11.28	10.47	13.33
2 1/8	12.06	15.35	13.31	12.71	11.82	15.05
2 1/4	13.52	17.22	14.92	14.24	13.25	16.88
2 3/8	15.07	19.18	16.62	15.88	14.77	18.80
2 1/2	16.69	21.25	18.42	17.65	16.36	20.83
2 5/8	18.40	23.43	20.31	19.45	18.04	22.97
2 3/4	20.20	25.71	22.29	21.28	19.80	25.21
2 7/8	22.07	28.10	24.36	23.28	21.64	27.55
3	24.03	30.60	26.53	25.36	23.56	30.00
3 1/8	26.08	33.20	28.78	27.50	25.57	32.55
3 1/4	28.20	35.92	31.10	29.28	27.65	35.21
3 3/8	30.42	38.78	33.57	32.10	29.82	37.97
3 1/2	32.71	41.65	36.10	34.56	32.07	40.83
3 5/8	35.09	44.68	38.73	37.05	34.40	43.80
3 3/4	37.56	47.82	41.45	39.68	36.82	46.88
3 7/8	40.10	51.05	44.26	42.35	39.31	50.05
4	42.73	54.40	47.16	45.12	41.89	53.33

WEIGHTS OF BRASS, COPPER AND ALUMINUM BARS PER LINEAR FOOT

Dia. or Distance Across Flats	Brass			Copper		Aluminum	
	Weight per Foot			Weight per Foot		Weight per Foot	
	Round	Square	Hexagon	Round	Square	Round	Square
$\frac{1}{16}$	.011	.014	.013	.012	.015	.003	.004
$\frac{1}{8}$	.045	.055	.048	.047	.060	.014	.018
$\frac{3}{16}$	.100	.125	.108	.106	.135	.032	.041
$\frac{1}{4}$	.175	.225	.194	.189	.241	.057	.072
$\frac{5}{16}$	.275	.350	.301	.296	.377	.089	.114
$\frac{3}{8}$	.395	.510	.436	.426	.542	.128	.163
$\frac{7}{16}$	.540	.690	.592	.579	.737	.174	.222
$\frac{1}{2}$	.710	.905	.773	.757	.964	.227	.290
$\frac{9}{16}$	.900	1.15	.978	.958	1.22	.288	.367
$\frac{5}{8}$	1.10	1.40	1.24	1.18	1.51	.356	.453
$\frac{11}{16}$	1.35	1.72	1.45	1.43	1.82	.430	.548
$\frac{3}{4}$	1.66	2.05	1.73	1.70	2.17	.516	.652
$\frac{13}{16}$	1.85	2.40	2.03	2.00	2.54	.601	.766
$\frac{7}{8}$	2.15	2.75	2.36	2.32	2.95	.697	.888
$\frac{15}{16}$	2.48	3.15	2.71	2.66	3.39	.800	1.02
1	2.85	3.65	3.10	3.03	3.86	.911	1.16
$1\frac{1}{16}$	3.20	4.08	3.49	3.42	4.35	1.03	1.31
$1\frac{1}{8}$	3.57	4.55	3.91	3.81	4.88	1.15	1.47
$1\frac{3}{16}$	3.97	5.08	4.38	4.27	5.44	1.28	1.64
$1\frac{1}{4}$	4.41	5.65	4.82	4.72	6.01	1.42	1.81
$1\frac{5}{16}$	4.86	6.22	5.33	5.21	6.63	1.57	2.00
$1\frac{3}{8}$	5.35	6.81	5.76	5.72	7.24	1.72	2.19
$1\frac{7}{16}$	5.86	7.45	6.38	6.26	7.97	1.88	2.40
$1\frac{1}{2}$	6.37	8.13	6.92	6.81	8.67	2.05	2.61
$1\frac{9}{16}$	6.92	8.83	7.54	7.39	9.41	2.22	2.83
$1\frac{5}{8}$	7.48	9.55	8.15	7.99	10.18	2.41	3.06
$1\frac{11}{16}$	8.05	10.27	8.80	8.45	10.73	2.59	3.30
$1\frac{3}{4}$	8.65	11.00	9.47	9.27	11.80	2.79	3.55
$1\frac{13}{16}$	9.29	11.82	10.15	9.76	12.43	2.99	3.81
$1\frac{7}{8}$	9.95	12.68	10.86	10.64	13.55	3.20	4.08
$1\frac{15}{16}$	10.58	13.50	11.68	11.11	14.15	3.41	4.35
2	11.25	14.35	12.36	12.11	15.42	3.64	4.64
$2\frac{1}{8}$	12.78	16.27	13.92	13.67	17.42	4.11	5.24
$2\frac{1}{4}$	14.32	18.24	15.72	15.33	19.51	4.61	5.87
$2\frac{3}{8}$	15.96	20.32	17.52	17.08	21.74	5.14	6.54
$2\frac{1}{2}$	17.68	22.53	19.44	18.92	24.09	5.69	7.25
$2\frac{5}{8}$	19.50	24.83	21.24	20.86	26.56	6.27	7.99
$2\frac{3}{4}$	21.40	27.25	23.40	22.89	29.05	6.89	8.53
$2\frac{7}{8}$	23.39	29.78	25.82	25.02	31.86	7.52	9.58
3	25.47	32.43	27.84	27.24	34.69	8.20	10.44
$3\frac{1}{4}$	30.45	38.77	32.76	31.97	40.71	9.62	12.25
$3\frac{1}{2}$	35.31	44.96	37.80	37.08	47.22	11.16	14.21
$3\frac{3}{4}$	40.07	51.01	43.56	42.11	53.61	12.81	16.31
4	46.12	58.73	49.44	48.43	61.67	14.56	18.56

WEIGHTS OF FLAT SIZES OF STEEL IN POUNDS PER LINEAR FOOT

	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2	1 3/4	2	2 1/4	2 1/2	2 3/4	3	3 1/2	4	5	6
1/8	.213	.266	.320	.372	.426	.479	.530	.585	.640	.745	.850	.955	1.07	1.18	1.28	1.49	1.70	2.13	2.56
3/16	.319	.399	.480	.558	.639	.718	.790	.878	.960	1.12	1.28	1.43	1.60	1.76	1.92	2.24	2.55	3.20	3.83
1/4	.425	.533	.640	.743	.852	.958	1.06	1.17	1.28	1.49	1.70	1.91	2.13	2.34	2.56	2.98	3.40	4.26	5.11
5/16	.531	.665	.800	.929	1.06	1.20	1.33	1.46	1.60	1.86	2.13	2.39	2.66	2.92	3.19	3.72	4.25	5.32	6.38
3/8	.638	.798	.960	1.12	1.28	1.43	1.59	1.75	1.91	2.23	2.55	2.87	3.20	3.51	3.83	4.46	5.10	6.40	7.66
7/16	.744	.931	1.12	1.30	1.49	1.67	1.86	2.05	2.23	2.60	2.98	3.35	3.72	4.09	4.46	5.21	5.95	7.44	8.92
1/2	..	1.07	1.28	1.49	1.70	1.91	2.13	2.34	2.55	2.98	3.40	3.83	4.26	4.68	5.10	5.96	6.80	8.52	10.20
9/16	..	1.20	1.44	1.67	1.91	2.15	2.39	2.63	2.87	3.35	3.83	4.30	4.78	5.26	5.74	6.69	7.65	9.56	11.50
5/8	..	..	1.60	1.86	2.12	2.39	2.66	2.92	3.19	3.72	4.26	4.79	5.32	5.86	6.39	7.44	8.52	10.64	12.78
11/16	..	..	1.76	2.04	2.34	2.63	2.92	3.22	3.51	4.09	4.68	5.26	5.84	6.43	7.01	8.18	9.35	11.70	14.00
3/4	..	..	..	2.23	2.55	2.86	3.19	3.50	3.83	4.46	5.10	5.74	6.40	7.02	7.65	8.92	10.20	12.80	15.30
13/16	..	..	..	2.41	2.76	3.11	3.45	3.80	4.14	4.83	5.53	6.22	6.91	7.60	8.29	9.67	11.10	13.80	16.60
7/8	..	..	..	..	2.98	3.34	3.72	4.09	4.46	5.21	5.96	6.70	7.46	8.19	8.94	10.42	11.92	14.92	17.88
15/16	..	..	..	..	3.19	3.59	3.98	4.38	4.78	5.58	6.38	7.17	7.97	8.77	9.56	11.20	12.80	15.90	19.10
1	..	..	..	..	..	3.82	4.25	4.68	5.10	5.96	6.80	7.66	8.52	9.36	10.20	11.92	13.60	17.04	20.40
1 1/8	..	..	..	..	..	..	4.78	5.27	5.74	6.71	7.65	8.61	9.59	10.54	11.48	13.41	15.30	19.17	22.95
1 1/4	..	..	..	..	..	..	..	5.85	6.38	7.45	8.50	9.57	10.65	11.71	12.76	14.90	17.00	21.30	25.61
1 1/2	..	..	..	..	..	..	..	7.02	7.67	8.94	10.20	11.49	12.78	14.04	15.30	17.88	20.40	25.56	30.

WEIGHTS OF SEAMLESS BRASS TUBING PER LINEAR FOOT. ($\frac{1}{8}$ TO $2\frac{1}{2}$ OUTSIDE DIAMETER. NOS. 1 TO 25 STUBS GAGE)

No. of Gage	Thickness in Inches	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$
1	.300	..	..	..	..	..	..	..	..	..	..	..	2.42	3.28	4.10	5.03	5.88	6.75	7.62
2	.284	..	..	..	..	..	..	..	..	..	..	..	2.35	3.16	4.03	4.80	5.57	6.45	7.26
3	259	..	..	..	..	..	..	..	..	..	..	1.85	2.22	2.98	3.72	4.48	5.23	5.96	6.72
4	.238	..	..	..	..	..	..	..	..	..	..	1.76	2.10	2.79	3.49	4.18	4.82	5.51	6.25
5	.220	..	..	..	..	..	..	..	..	..	..	1.68	1.99	2.60	3.26	3.89	4.53	5.14	5.80
6	.203	..	..	..	..	..	..	..	..	1.00	1.29	1.58	1.88	2.46	3.04	3.60	4.20	4.80	5.39
7	.180	..	..	..	..	..	..	..	..	.90	1.19	1.44	1.71	2.23	2.77	3.28	3.78	4.33	4.83
8	.165		..	..	..	.40	.52	.64	.77	.87	1.11	1.35	1.59	2.07	2.54	3.02	3.50	3.98	4.46
9	.148	..	..	..	..	.39	.49	.61	.71	.82	1.04	1.25	1.46	1.89	2.32	2.75	3.17	3.60	4.03
10	.134	..	..	..	..	.38	.46	.58	.65	.77	.96	1.16	1.35	1.74	2.12	2.51	2.90	3.28	3.67
11	.120	..	..	.18	.26	.36	.43	.53	.61	.70	.87	1.05	1.22	1.57	1.91	2.27	2.16	2.96	3.31
12	.109	..	..	.177	.256	.334	.413	.491	.570	.650	.808	.965	1.12	1.43	1.76	2.07	2.39	2.70	3.01
13	.095	..	..	.170	.237	.306	.377	.445	.514	.580	.717	.855	1.00	1.27	1.55	1.82	2.09	2.37	2.65
14	.083	..	..	.160	.220	.280	.340	.400	.460	.520	.640	.760	.88	1.12	1.36	1.61	1.84	2.08	2.32
15	.072	..	.096	.144	.201	.251	.303	.355	.409	.461	.564	.667	.77	.99	1.19	1.40	1.61	1.81	2.02
16	.065	..	.092	.138	.186	.232	.279	.326	.372	.420	.515	.609	.70	.89	1.07	1.26	1.45	1.64	1.82
17	.058	.044	.087	.128	.169	.212	.255	.295	.338	.380	.463	.548	.64	.80	.97	1.14	1.30	1.48	1.64
18	.049	.043	.078	.113	.150	.183	.220	.255	.291	.325	.397	.467	.54	.67	.82	.96	1.10	1.24	1.39
19	.042	.040	.070	.101	.130	.161	.193	.221	.252	.282	.343	.404	.46	.58	.71	.83	.95	1.07	1.19
20	.035	.036	.062	.086	.113	.136	.163	.188	.214	.238	.289	.339	.39	.49	.59	.69	.80	.893	1.00
21	.032	.034	.057	.081	.104	.128	.151	.173	.196	.219	.266	.312	.357	.450	.542	.635	.727	.820	.913
22	.028	.031	.051	.072	.093	.112	.133	.152	.174	.192	.233	.275	.315	.396	.477	.556	.638	.718	.799
23	.025	.029	.047	.066	.082	.102	.119	.136	.155	.173	.209	.245	.281	.354	.426	.497	.571	.641	.714
24	.022	.026	.042	.058	.074	.090	.107	.121	.137	.154	.186	.218	.249	.312	.376	.438	.502	.566	.629
25	.020	.024	.039	.052	.068	.081	.096	.110	.126	.140	.169	.197	.226	.285	.342	.399	.457	.516	.573

For Weights of Seamless Copper Tubing, add 5 per cent. to the weights above.

"SHELBY" COLD-DRAWN SEAMLESS STEEL TUBING—ROUND
(Weight in Pounds per Foot)

Thickness B.W.G. & Fractions	Equivalent in Decimal of Inch	OUTSIDE DIAMETER IN INCHES																		
		½	⅝	¾	⅞	1	1⅛	1¼	1⅜	1½	1⅝	1¾	1⅞	2	2⅛	2¼	2⅜	2½	2⅝	2¾
20	0.035	0.17	0.22	0.27	0.31	0.36	0.41	0.45												
18	0.049	0.24	0.30	0.37	0.43	0.50	0.56	0.63	0.69	0.76	0.82									
16	0.065	0.30	0.39	0.47	0.56	0.65	0.74	0.82	0.91	1.00	1.08	1.17	1.26	1.34	1.43	1.52	1.60	1.69		
14	0.083	0.37	0.48	0.59	0.70	0.81	0.92	1.03	1.14	1.25	1.37	1.48	1.59	1.70	1.81	1.92	2.03	2.14	2.25	2.36
13	0.090	0.41	0.54	0.66	0.79	0.92	1.04	1.17	1.30	1.42	1.55	1.68	1.80	1.93	2.06	2.19	2.31	2.44	2.56	2.69
12	0.109	0.45	0.60	0.75	0.89	1.04	1.18	1.33	1.47	1.62	1.76	1.91	2.06	2.20	2.35	2.49	2.63	2.78	2.93	3.07
11	0.120	0.49	0.65	0.81	0.97	1.13	1.29	1.45	1.61	1.77	1.93	2.09	2.25	2.41	2.57	2.73	2.89	3.05	3.21	3.37
10	0.134	0.52	0.70	0.88	1.06	1.24	1.42	1.60	1.77	1.95	2.13	2.31	2.49	2.67	2.85	3.03	3.21	3.39	3.56	3.74
5/32	0.156			0.99	1.20	1.41	1.61	1.82	2.03	2.24	2.45	2.66	2.87	3.07	3.28	3.49	3.70	3.91	4.12	4.32
3/16	0.188			1.13	1.38	1.63	1.88	2.13	2.38	2.63	2.88	3.13	3.38	3.63	3.88	4.13	4.38	4.63	4.88	5.13
7/32	0.219				1.53	1.82	2.12	2.41	2.70	2.99	3.28	3.57	3.87	4.16	4.48	4.74	5.03	5.32	5.62	5.91
¼	0.250					2.00	2.33	2.67	3.00	3.33	3.67	4.00	4.33	4.67	5.00	5.33	5.67	6.00	6.33	6.67
9/32	0.281							2.91	3.28	3.66	4.03	4.41	4.78	5.16	5.53	5.91	6.28	6.66	7.03	7.41
5/16	0.313							3.13	3.54	3.96	4.38	4.79	5.21	5.63	6.04	6.46	6.88	7.29	7.71	8.13
⅜	0.375							3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.50	7.00	8.00	8.50	9.00	9.51
7/16	0.438								4.38	4.96	5.54	6.13	6.71	7.29	7.88	8.46	9.04	9.63	10.21	10.79
½	0.500									5.33	6.00	6.67	7.33	8.00	8.67	9.34	10.00	10.67	11.34	12.00
9/16	0.562											7.13	7.88	8.63	9.38	10.13	10.88	11.63	12.38	13.13
⅝	0.625													9.17	10.00	10.84	11.67	12.50	13.34	14.17
¾	0.750																	14.00	15.00	16.00
⅞	0.875																			
1"	1.000																			

Hot rolled from 2-inch diameter No. 11 gage to 9 inches and 1 inch thick. Same weights as above.

DECIMAL THICKNESS TABLE FOR SHEET COPPER

Sheet copper is frequently designated by the weight in ounces of a square foot instead of by its thickness. This table prevents the necessity of weighing and measuring.

THICKNESS OF COPPER FROM 3 TO 253 OUNCES PER SQUARE FOOT

Ounces per Square Foot	Decimal Thickness, Inches	Ounces per Square Foot	Decimal Thickness, Inches
3	0.004	64	0.083
4	0.005	70	0.095
6	0.008	81	0.109
8	0.010	89	0.120
10	0.013	100	0.134
12	0.016	110	0.148
14	0.018	123	0.165
16	0.022	134	0.180
18	0.025	151	0.203
20	0.028	164	0.220
24	0.032	177	0.238
32	0.042	193	0.259
40	0.049	211	0.284
48	0.065	223	0.300
56	0.072	253	0.340

Buffalo, N. Y. H. B. KELLAM

GAGES USED IN U. S. FOR DIFFERENT MATERIAL

Name of Gage	Used for Gaging
American Wire or Brown & Sharpe.............	Brass, bronze, copper and other non-ferrous wires and sheets
Birmingham, or Stub's iron wire.............	Telegraph and telephone wire. Also to some extent for non-ferrous sheets and the wall thickness of tubing.
Music wire.............	Piano and other music wire
Sheet zinc..............	Zinc sheets
Steel wire, or Washburn Moen................	Steel wire except music wire and drill rod
Twist drill and steel wire	Twist drills and drill rods
U. S. Standard for sheets and plates............	Sheet and plate iron and steel—really more of a gage of weight per square foot than of thickness

GAGE AND WEIGHT OF ZINC SHEET

Sheet zinc rolled in the U. S. is measured by the American Standard zinc gage. The table is supplied by the Illinois Zinc Company. The numbers run opposite to most metal gages, the smaller numbers being the thinnest metal.

ILLINOIS ZINC COMPANY'S ZINC GAGE

No.	Lbs. per Square Foot	Thickness in Inches	No.	Lbs. per Square Foot	Thickness in Inches
3	0.22	0.006	16	1.68	0.045
4	0.30	0.008	17	1.87	0.050
5	0.37	0.010 $\frac{1}{100}$	18	2.06	0.055
6	0.45	0.012	19	2.25	0.060 $\frac{1}{17}$
7	0.52	0.014	20	2.62	0.070
8	0.60	0.016	21	3.00	0.080
9	0.67	0.018	22	3.37	0.090
10	0.75	0.020 $\frac{1}{50}$	23	3.75	0.100 $\frac{1}{10}$
11	0.90	0.024	24	4.70	0.125 $\frac{1}{8}$
12	1.05	0.028	25	9.40	0.250 $\frac{1}{4}$
13	1.20	0.032	26	14.00	0.375 $\frac{3}{8}$
14	1.35	0.036	27	18.75	0.500
15	1.50	0.040 $\frac{1}{25}$	28	37.50	1.000

TOLERANCES ON COMMERCIAL MATERIALS

Drill Rod.—Commercial tolerance on ground drill rod is plus or minus 0.0005 inch in practically all sizes up to 1 inch. On special order this tolerance can be about cut in half. On cold drawn drill rod the tolerance is generally plus or minus 0.001 inch. (Anchor Drawn Steel Company.)

Cold Drawn Seamless Tubing.—Tolerances vary with the size of the tube and with the finish. On smaller tubes the O. D. tolerance is all plus and the I. D. all minus. Wall tolerance is given in percentages. This refers to round tubes. Greater tolerances are usually found in rectangular tubes. Details of tolerances on cold drawn round tubes of the National Tube Company are given in Table 1, page 961.

TABLE I.—TOLERANCES ON ROUND, COLD DRAWN SEAMLESS MECHANICAL TUBING

Group No.	Size of Tube	O.D. Tolerances	I.D. Tolerances	Wall Tolerances
1	Less than ½-inch I.D.	Plus 0.005 inch, minus 0.0 (See Note 4)	(See Note 2)	(See Note 2)
2	½-inch I.D. to, but not including, 1½ inches O.D., nor sizes in group No. 1	Plus 0.005 inch, minus 0.0 (See Note 4)	Plus 0.0, minus 0.005 inch (See Note 1)	Plus and minus 10 per cent (See Note 1)
3	1½ to, but not including, 3½ inches O.D.	Plus 0.010 inch, minus 0.0 (See Note 4)	Plus 0.0, minus 0.010 inch (See Note 1)	Plus and minus 10 per cent (See Note 1)
4	3½ to, but not including, 5½ inches O.D.	Plus 0.015 inch, minus 0.0 (See Note 4)	Plus and minus 0.010 inch (See Note 1)	Plus and minus 10 per cent (See Note 1)
5	5½ to 9 inches O.D. when wall is less than 5 per cent of O.D.	Plus and minus 1 per cent of O.D.	(See Note 3)	Plus and minus 10 per cent
6	5½ to 9 inches O.D. when wall is at least 5, and not more than, 7½ per cent of O.D.	Plus and minus ¾ per cent of O.D.	(See Note 3)	Plus and minus 10 per cent
7	5½ to 9 inches O.D. when wall is over 7½ per cent of O.D.	Plus ½ per cent of O.D., minus 0.0	(See Notes 1 and 3)	Plus and minus 10 per cent (See Note 1)

IMPORTANT.—The above O.D., I.D., and wall tolerances *apply only* to *normal sizes* and to *unannealed and finish annealed* tubing. Tubes having relatively heavy or light walls in relation to the O.D. are covered by special tolerances, reference to which is made in Footnotes 1 to 4 of this table. Finish and unannealed tubing constitute the bulk of *cold drawn mechanical tubing*. Tubing which has been given the softer anneals is apt to possess more or less ovality due to straightening and warpage in annealing. The greater degree of heat used in the softer anneals with the attendant increase in scale also affects the accuracy of size. Hence, medium and soft annealed tubing will not be as close to size as the table indicates.

In all dimensional values of a manufactured article more or less variation exists. It is customary to set limits beyond which these dimensional variations may not go. Such limits are called "tolerances."

NOTE 1: Tubes having an I.D. less than 60 per cent of the O.D. or having a wall ¾ inch and heavier cannot be successfully drawn over a mandrel. The I.D. of such sizes may vary plus or minus 10 per cent of the wall. The wall of such sizes may vary plus or minus 12½ per cent.

NOTE 2: Tubes less than ½-inch I.D. cannot be successfully drawn over a mandrel. Consequently, the wall may vary plus or minus 25 per cent and the I.D. will be governed by the O.D. and wall variations.

NOTE 3: On larger diameters with light walls the warpage on annealing and ovality resulting from straightening cause the use of slightly wider tolerances. In such cases the I.D. variation will be governed by O.D. and wall variations.

NOTE 4: Tubing up to 5½ inches O.D. and having a wall which is 3 per cent, or less than 3 per cent, of the O.D. cannot be straightened properly without a certain amount of ovality resulting in the diameter. Consequently, such tubes, while having an *average* O.D. and I.D. within the tolerances shown in the table will require an ovality tolerance of plus and minus ½ per cent of the average diameter on the O.D. and I.D., this being in addition to the tolerances indicated in the table.

THICKNESS TOLERANCE

(American Rolling Mill Co.)

The following tables show the plus or minus variation from ordered thickness on sheets ordered by decimal thickness:

Ordered Thickness	Permissible Variation from Ordered Thickness on All Sheets over 42 Inches Wide, As Well As All Sheets Rolled on Hand Mills
0.250 and thicker	0.016
0.220 to 0.249	0.015
0.190 to 0.219	0.014
0.160 to 0.189	0.013
0.140 to 0.159	0.012
0.120 to 0.139	0.011
0.100 to 0.119	0.010
0.080 to 0.099	0.009
0.070 to 0.079	0.008
0.060 to 0.069	0.007
0.050 to 0.059	0.006
0.040 to 0.049	0.005
0.030 to 0.039	0.004
Lighter than 0.030	0.003

Ordered Thickness	Permissible Variation from Ordered Thickness on All Sheets 42 Inches Wide and Less Rolled on Continuous Mills
0.110 and heavier	0.01
0.079 to 0.109	0.007
0.057 to 0.c78	0.005
0.045 to 0.056	0.004
0.018 to 0.044	0.003
0.0125 to 0.017	0.002

While material ordered by thickness is subject to inspection by thickness only, and not by weight, yet it is reasonable to expect that over large quantities the average weight will come within the weight tolerance for the weight and width of material ordered.

WEIGHT TOLERANCE

When ordered by weight per square feet, sheets shall conform to the following tables:

Ordered Gage Weight	Permissible Variation from Ordered Gage Weight, on Sheets 42 Inches Wide and Less in Percentage of Estimated Weight		
	All of One Gage and Size in Shipment,	Single Package, Per Cent	Single Sheet, Per Cent
16 gage and heavier	5.0	7.0	10.0
17 to 22 gage, inclusive	3.5	5.5	10.0
23 gage and lighter	2.5	4.0	10.0

Ordered Gage Weight	Permissible Variation from Ordered Gage Weight, on Sheets Over 42 Inches Wide, in Percentage of Estimated Weigh		
	All of One Gage and Size in Shipment, Per Cent	Single Package, Per Cent	Single Sheet, Per Cent
16 gage and heavier	7.0	9.0	12.0
17 to 22 gage, inclusive	5.5	7.5	12.0
23 gage and lighter	4.5	6.0	12.0

THICKNESS IN FRACTIONS OF AN INCH

Fractions of Inch	Equivalent Thickness in Decimal Points of an Inch	Embracing the Following Gage Ranges	Average Weight per Square Feet Hot Rolled or Cold Rolled Steel Sheets Resquared	Average Weight per Square Feet Hot Rolled Sheets Not Resquared	Average Weight per Square Feet Cold Rolled Sheets Not Resquared
9/64	0.140	10	5.7375	5.8236	5.9096
1/8	0.125	11	5.1	5.1765	5.253
7/64	0.109	12	4.4625	4.5294	4.5964
3/32	0.093	13	3.825	3.8824	3.9398
5/64	0.078	14	3.1875	3.2353	3.2831
9/128	0.070	15	2.86875	2.9118	2.9548
1/16	0.0625	16	2.55	2.5883	2.6265
9/160	0.056	17	2.295	2.3294	2.3639
1/20	0.050	18	2.04	2.0706	2.1012
7/160	0.043	19	1.785	1.8118	1.8386
3/80	0.0375	20	1.53	1.5530	1.5759
11/320	0.034	21	1.4025	1.4325	1.4446
1/32	0.0312	22	1.275	1.2941	1.3133
9/320	0.028	23	1.1475	1.1647	1.1819
1/40	0.025	24	1.02	1.0353	1.0506
7/320	0.021	25	0.8925	0.9059	0.9193
3/160	0.018	26	0.765	0.7765	0.7880
11/640	0.017	27	0.70125	0.7118	0.7223
1/64	0.0156	28	0.6375	0.6471	0.6566

Commercial Tolerances

Latrobe Electric Steel Company furnish tool bits for lathe, planer, or similar tools to a tolerance of plus or minus 0.006 inch. On special shapes hot rolled up to 1 inch, round or square, the tolerance is plus or minus 0.008 inch. Over 1 inch the tolerance is plus or minus 0.012 inch. Cold drawn steel is furnished up to 5/8 inch round or square with a tolerance of plus or minus 0.001 inch. On larger sizes the tolerance is 0.002 inch.

TOLERANCES OF BRASS AND COPPER TUBING (WOLVERINE TUBE CO.)

Variation in Diameter Outside or Inside	Variation in Wall	Variation in Length	Variation in Coiled Lengths
UP TO 1/2" .0020"	UP TO .018"-.001"	UP TO 6 FEET-1/32"	UP TO 10 FEET-1/2"
1/2" " 3/4" .0025"	.019" " .035"-.002"	6.01" " 8 " - 1/16"	10" " 18 " - 1"
3/4" " 1" .0030"			
1" " 1 1/4" .0035"	.036" " .109"-.003"	8.01" " 10 - 3/32"	
1 1/4" " 1 1/2" .0040"	.110" " .186"-.004"	10.01 AND LONGER-1/8"	18" AND LONGER - 6"
1 1/2" " 1 3/4" .0045"			
All Tolerances Plus or Minus			

Commercial Tolerances on Steel Balls

(Hoover Steel Ball Company)

Grade and Size	Spherical Within, in Inches
Sizes $\frac{1}{8}$ to $1\frac{15}{16}$ inches:	
Grade No. 1 chrome steel balls (formerly micro chrome grade)	0.000025
Grade No. 2 chrome steel balls (formerly standard grade)	0.00005
Grade No. 3 chrome steel balls (formerly "A" grade)	0.0002
Hardware grade chrome steel balls	0.001
Sizes 2 to $2\frac{7}{8}$ inches:	
Grade No. 1 chrome steel balls (formerly micro chrome grade)	0.00005
Grade No. 2 chrome steel balls (formerly standard grade)	0.0002
Grade No. 3 chrome steel balls (formerly "A" grade)	0.0005
Hardware grade chrome steel balls	0.001
Sizes 3 inches and larger:	
Grade No. 1 chrome steel balls (formerly micro chrome grade)	0.00005
Grade No. 2 chrome steel balls (formerly standard grade)	0.0002
Grade No. 3 chrome steel balls (formerly "A" grade)	0.0005
Hardware grade chrome steel balls	0.001
Stainless steel balls, diameter: up to $\frac{5}{8}$ inch	0.0001
Stainless steel balls, diameter: $\frac{11}{16}$ to 2 inches	0.0001
Stainless steel balls, diameter: over 2 inches	0.0002
Brass and bronze balls	0.0002
Monel metal balls	0.0002

Commercial Tolerances

SPECIAL-ACCURACY SCREW STOCK

This screw-stock quality is suitable for requirements of extreme accuracy and polished finish, furnished within a tolerance of 0.0005 inch plus or minus. Sizes range from $\frac{3}{32}$ up to $1\frac{1}{2}$ inches.

PISTON-ROD STOCK

Where work calls for shafting true to round, precise in size, straight and free from surface imperfections, this stock is suitable. It is especially suited for all close work in pump building. This shafting runs from exact size to not more than 0.002 inch undersize. Ordinary sizes run from $\frac{3}{4}$ to $1\frac{3}{8}$ inches diameter.

Tolerances for Hot-Rolled Steel—Rounds, Squares, Hexagons

Size, in Inches	Variation	
Up to and including $\frac{1}{2}$	Under 0.007	Over 0.007
Over $\frac{1}{2}$, up to and including 1	Under 0.010	Over 0.010
Over 1, up to and including 2	Under $\frac{1}{64}$	Over $\frac{1}{32}$
Over 2, up to and including 3	Under $\frac{1}{32}$	Over $\frac{3}{64}$
Over 3, up to and including 5	Under $\frac{1}{32}$	Over $\frac{3}{32}$
Over 5, up to and including 8	Under $\frac{1}{16}$	Over $\frac{1}{8}$

Tolerances of Cold-Drawn Steel

Cold-drawn steels can be used economically in much machine construction. Close tolerances are held so that further finish is frequently unnecessary. The Union Drawn Steel division of the Republic Steel Company gives these tolerances on round bars: $\frac{5}{16}$ to 1 inch, −0.002 inch; $1\frac{1}{8}$ to 2 inches, −0.003 inch; over 2 inches, −0.004 inch.

Other shapes, such as squares, flats, and hexagons, are held concentric within 0.001 inch on bars up to 1 inch. Irregular sections that require no machining of the contour except cutting-off can be used to save machining time.

MANUFACTURING TOLERANCES

(Jos. T. Ryerson and Son)

Cold-Finished Steel Bars (Bessemer and Open-Hearth Screw Stock and Special Open-Hearth Specifications, 0.50 Per Cent Carbon and Less)

Diameter, in Inches	Variation in size, in Inches			
	Rounds and Hexagons		Squares	
	Under	Over	Under	Over
Up to 0.3 inclusive	0.002	0	0.003	0
Over 0.3 to 1 inclusive	0.003	0	0.004	0
Over 1 to 2½ inclusive	0.004	0	0.005	0
Over 2½ to 6 inclusive	0.005	0	0.006	0

Thickness, in Inches	Flats, in Inches			
	Up to 1½ Inches Wide		Over 1½ Inches Wide	
	Under	Over	Under	Over
Up to 0.3 inclusive	0.003	0	0.005	0
Over 0.3 to 1 inclusive	0.004	0	0.005	0
Over 1 to 2½ inclusive	0.005	0	0.006	0
Over 2½ to 4 inclusive	.....	..	0.007	0
Over 4 to 6 inclusive	.....	..	0.010	0

The tolerances on flats apply to thickness as well as width

For Shafting

	Under, in Inches	Over
Up to 1 inch inclusive	0.002	0
Over 1 to 2 inches inclusive	0.003	0
Over 2 to 4 inches inclusive	0.004	0
Over 4 to 6 inches inclusive	0.005	0

SECTION XX

HORSE-POWER, BELTS, AND SHAFTING

Horse-Power

Horse-power is an arbitrary unit of measurement which has been adopted for measuring the work of engines or machines. It is given as 33,000 foot pounds per minute which means 1 pound lifted 33,000 feet per minute or 33,000 pounds lifted 1 foot per minute or 330 pounds lifted 100 feet per minute, or any combination which gives 33,000 foot pounds per minute.

Steam Engine Horse-Power

In a steam engine it means the effective steam pressure per square inch, times the length of piston movement per revolution in feet, times the piston area in square inches, times the number of revolutions per minute, and all divided by 33,000. This is easily remembered by the formula

$$\frac{PLAN}{33{,}000} = \text{H.P.}$$

where P = mean effective pressure per square inch.
L = length of a double stroke in feet.
A = area of piston in square inches.
N = number of revolutions per minute.

Electrical Power

As compared with electrical units the mechanical horse-power equals 746 watts or nearly ¾ of a kilowatt, so that a kilowatt (1,000 watts) equals 1.34 horse-power.

Gas Engine Horse-Power

The A.L.A.M. rating for gasoline engines, which means the rating adopted by the American Licensed Automobile Manufacturers, is based on the assumption that the piston speed is 1,000 feet per minute in all cases. This gives 1,500 revolutions per minute for a 4-inch stroke motor, which is about average practice. Since the defeat of the Selden patent, the A.L.A.M. has ceased to exist, and the standard is now known as the S.A.E. standard (Society of Automotive Engineers).

S.A.E. (A.L.A.M.) Horse-Power Rating

The formula adopted is $\frac{D^2 \times N}{2.5}$ and is based on 1,000 feet per minute piston speed. D is the cylinder bore, N the number of cylinders, and 2.5 a constant based on the average view of the Mechanical Branch as to a fair conservative rating.

TABLE 1.—HORSE-POWER FOR USUAL SIZES OF MOTORS, BASED ON S.A.E. (A.L.A.M.) FORMULA

BORE		HORSE-POWER				
Ins.	M/M	1 Cyl.	2 Cyls.	4 Cyls.	6 Cyls.	8 Cyls.
$2\frac{1}{2}$	64	$2\frac{1}{2}$	5	10	15	20
$2\frac{5}{8}$	68	$2\frac{3}{4}$	$5\frac{1}{2}$	11	$16\frac{1}{2}$	22
$2\frac{3}{4}$	70	3	6	$12\frac{1}{10}$	$18\frac{1}{8}$	$24\frac{2}{10}$
$2\frac{7}{8}$	73	$3\frac{5}{16}$	$6\frac{5}{8}$	$13\frac{1}{4}$	$19\frac{7}{8}$	$26\frac{1}{2}$
3	76	$3\frac{3}{5}$	$7\frac{1}{5}$	$14\frac{2}{5}$	$21\frac{3}{5}$	$28\frac{4}{5}$
$3\frac{1}{8}$	79	$3\frac{15}{16}$	$7\frac{13}{16}$	$15\frac{5}{8}$	$23\frac{7}{16}$	$31\frac{1}{4}$
$3\frac{1}{4}$	83	$4\frac{1}{4}$	$8\frac{1}{2}$	$16\frac{9}{10}$	$25\frac{2}{5}$	$33\frac{4}{5}$
$3\frac{3}{8}$	85	$5\frac{9}{16}$	$9\frac{1}{8}$	$18\frac{1}{4}$	$27\frac{2}{5}$	$36\frac{1}{2}$
$3\frac{1}{2}$	89	$4\frac{9}{10}$	$9\frac{4}{5}$	$19\frac{3}{5}$	$29\frac{2}{5}$	$39\frac{1}{5}$
$3\frac{5}{8}$	92	$5\frac{1}{4}$	$10\frac{1}{2}$	$20\frac{1}{4}$	$31\frac{3}{6}$	$40\frac{1}{2}$
$3\frac{3}{4}$	95	$5\frac{5}{8}$	$11\frac{1}{4}$	$22\frac{1}{2}$	$33\frac{3}{4}$	45
$3\frac{7}{8}$	99	6	12	24	$36\frac{1}{16}$	48
4	102	$6\frac{2}{5}$	$12\frac{4}{5}$	$25\frac{3}{5}$	$38\frac{2}{5}$	$51\frac{1}{5}$
$4\frac{1}{8}$	105	$6\frac{13}{16}$	$13\frac{5}{8}$	$27\frac{1}{4}$	$40\frac{9}{10}$	$54\frac{1}{2}$
$4\frac{1}{4}$	108	$7\frac{1}{4}$	$14\frac{1}{4}$	$28\frac{9}{10}$	$43\frac{4}{5}$	$57\frac{4}{5}$

To simplify reading of the above, the horse-power figures are approximate, but correct within one-sixteenth.

Table of Piston-Ring Data

The accompanying table, while not official, is complied with to a great extent in the machinery division of the United States navy yard, Boston, Mass. The sizes run very close to the average make of rings found in the commercial and naval engines of small cylinder bore.

This table is adaptable to ordinary snap rings that are to be rough-turned and bored, cut and drawn together, and finished to the diameter of the cylinder.

TABLE 2.—PISTON-RING DATA

Diameter of Cylinder, In.	Rough-turn Diameter of Ring, In.	Rough-bore Diameter of Ring, In.	Amount to Cut Out, In.	Width of Ring, In.	Thickness of Ring, In.
2	2 1/8	1 13/16	1/4	1/8	1/8
3	3 5/32	2 3/4	9/32	3/16	5/32
4	4 3/16	3 3/4	5/16	1/4	3/16
5	5 7/32	4 23/32	11/32	5/16	7/32
6	6 1/4	5 5/8	3/8	3/8	1/4
7	7 9/32	6 19/32	13/32	7/16	9/32
8	8 5/16	7 9/16	7/16	1/2	5/16
9	9 11/32	8 17/32	15/32	9/16	11/32
10	10 3/8	9 1/2	1/2	5/8	3/8
12	12 7/16	11 7/16	9/16	11/16	7/16
14	14 1/2	13 3/8	5/8	3/4	1/2
16	16 9/16	15 5/16	3/4	13/16	9/16
18	18 5/8	17 1/4	7/8	7/8	5/8
20	20 11/16	19 1/8	1	15/16	11/16
22	22 3/4	20 3/8	1 1/8	1	3/4
24	24 13/16	22 1/4	1 1/4	1 1/16	13/16
30	30 7/8	28	1 5/8	1 1/8	15/16
36	36 15/16	33 1/2	2	1 1/4	1 1/8

This covers general requirements on gasoline and steam engines.

HORSE-POWER RATINGS FOR FLAT LEATHER BELTS

Prepared by Lloyd H. Skougor, research engineer under the auspices of the American Leather Belting Association, the following horse-power rating tables for oak-tanned flat leather belting is a correlation of carefully measured test and field data. The values given in Table 3 do not represent peak-load ratings but are based on proper tensions and factors of safety. When these values are corrected with the factors in Tables 4 and 5, a properly designed drive will result. It is to be realized that conditions exist which may not be covered by these tables and exceptions must be made in those instances. When belt speeds are above 6,000 feet per minute, these tables do not apply, and a leather belting manufacturer should be consulted. Gravity idler and pivoted motor drives with the tight side of the belt next to the pivot point are considered as having 25 foot centers in determining a correction factor for center distance from Table 3. For pivot-base drives, where the tight side of the belt is away from the pivot point, do not use these tables, but consult a leather belting manufacturer.

To Find Width of Belt Required.—Divide nameplate reading of the prime mover, or the nominal load, by values in Tables 3, 4, and 5. **Width of belt = nominal load ÷ (value from Table 3 × correction factor from Table 4 × product of all correction factors selected from Table 5).**

TABLE 3.—HORSE-POWER PER INCH OF WIDTH

Belt Speed, Feet per Minute	Single Ply		Double Ply			Triple Ply	
	$\frac{11}{64}$	$\frac{13}{64}$	$\frac{18}{64}$	$\frac{20}{64}$	$\frac{23}{64}$	$\frac{30}{64}$	$\frac{34}{64}$
	Medium	Heavy	Light	Medium	Heavy	Medium	Heavy
600	1.1	1.2	1.5	1.8	2.2	2.5	2.8
800	1.4	1.7	2.0	2.4	2.9	3.3	3.6
1,000	1.8	2.1	2.6	3.1	3.6	4.1	4.5
1,200	2.1	2.5	3.1	3.7	4.3	4.9	5.4
1,400	2.5	2.9	3.5	4.3	4.9	5.7	6.3
1,600	2.8	3.3	4.0	4.9	5.6	6.5	7.1
1,800	3.2	3.7	4.5	5.4	6.2	7.3	8.0
2,000	3.5	4.1	4.9	6.0	6.9	8.1	8.9
2,200	3.9	4.5	5.4	6.6	7.6	8.8	9.7
2,400	4.2	4.9	5.9	7.1	8.2	9.5	10.4
2,600	4.5	5.3	6.3	7.7	8.9	10.3	11.0
2,800	4.9	5.6	6.8	8.2	9.5	11.0	12.1
3,000	5.2	5.9	7.2	8.7	10.0	11.6	12.8
3,200	5.4	6.3	7.6	9.2	10.6	12.3	13.5
3,400	5.7	6.6	7.9	9.7	11.2	12.9	14.2
3,600	5.9	6.9	8.3	10.1	11.7	13.4	14.8
3,800	6.2	7.1	8.7	10.5	12.2	14.0	15.4
4,000	6.4	7.4	9.0	10.9	12.6	14.5	16.0
4,200	6.7	7.7	9.3	11.3	13.0	15.0	16.5
4,400	6.9	7.9	9.6	11.7	13.4	15.4	16.9
4,600	7.1	8.1	9.8	12.0	13.8	15.8	17.4
4,800	7.2	8.3	10.1	12.3	14.1	16.2	17.8
5,000	7.4	8.4	10.3	12.5	14.3	16.5	18.2
5,200	7.5	8.6	10.5	12.8	14.6	16.8	18.5
5,400	7.6	8.7	10.6	12.9	14.8	17.1	18.8
5,600	7.7	8.8	10.8	13.1	15.0	17.3	19.0
5,800	7.7	8.9	10.9	13.2	15.1	17.5	19.2
6,000	7.8	8.9	10.9	13.2	15.2	17.6	19.3
Minimum Pulley Diameter in Inches: Belts under 8 inches wide	3	5	6	8	12	20	24
Minimum Pulley Diameter in Inches: Belts 8 inches and over wide	5	7	8	10	14	24	30

These are the minimum allowable pulleys for the above thickness belts.

TABLE 4.—CORRECTION FACTOR FOR CENTER DISTANCE AND SMALL PULLEY

Diameter of Small Pulley, in Inches	Center Distance, in Feet															
	Up to 4 Feet		6 Feet		8 Feet		10 Feet		12 Feet		15 Feet		20 Feet		25 Feet and Over	
	Tight Side		Tight Side		Tight Side		Tight Side		Tight Side		Tight Side		Tight Side		Tight Side	
	Above	Below	Above	Below	Above	Below	Above	Below	Above	Below	Above	Below	Above	Below	Above	Below
3	0.45	0.45	0.46	0.47	0.47	0.48	0.47	0.49	0.48	0.50	0.49	0.52	0.48	0.54	0.48	0.55
4	0.5	0.53	0.54	0.55	0.55	0.57	0.56	0.59	0.57	0.61	0.58	0.63	0.59	0.65	0.59	0.66
5	0.59	0.59	0.60	0.62	0.62	0.64	0.63	0.66	0.63	0.68	0.65	0.70	0.66	0.72	0.66	0.74
6	0.62	0.62	0.63	0.65	0.65	0.68	0.66	0.70	0.67	0.72	0.68	0.74	0.69	0.76	0.70	0.78
8	0.66	0.66	0.67	0.69	0.69	0.71	0.70	0.74	0.71	0.76	0.72	0.78	0.73	0.80	0.74	0.82
10	0.68	0.68	0.70	0.71	0.71	0.74	0.73	0.77	0.73	0.79	0.75	0.81	0.76	0.83	0.77	0.85
12	0.70	0.70	0.72	0.74	0.73	0.77	0.75	0.79	0.76	0.81	0.77	0.83	0.78	0.86	0.79	0.88
15	0.73	0.73	0.74	0.76	0.76	0.79	0.77	0.82	0.78	0.84	0.80	0.86	0.81	0.89	0.82	0.91
18	0.75	0.75	0.76	0.78	0.78	0.81	0.79	0.84	0.80	0.86	0.82	0.89	0.83	0.91	0.84	0.93
24	0.77	0.77	0.79	0.81	0.81	0.84	0.82	0.87	0.83	0.89	0.85	0.92	0.86	0.94	0.87	0.96
30	0.79	0.79	0.81	0.82	0.82	0.86	0.84	0.89	0.85	0.91	0.87	0.94	0.88	0.96	0.89	0.98
36	0.80	0.80	0.82	0.84	0.83	0.87	0.85	0.90	0.86	0.92	0.88	0.95	0.89	0.98	0.90	1.00

To Find Horse-Power Rating of a Belt.—Multiply belt width by values in Tables 3, 4, and 5. Horse-power rating = width of belt, in inches, × horse-power transmission capacity per inch of width from Table 3 × correction factor from Table 4 × product of all correction factors selected from Table 5.

TABLE 5.—SERVICE CORRECTION FACTORS

Atmospheric condition	Clean, scheduled maintenance	1.2
	Normal	1.0
	Oily, wet or dusty	0.7
Angle of center line	Horizontal to 60 deg. from horizontal	1.0
	From 60 to 75 deg. from horizontal	0.9
	From 75 to 90 deg. from horizontal	0.8
Pulley material	Fibre on motor and small pulleys	1.2
	Cast iron or steel	1.0
Service	Temporary or intermittent	1.2
	Normal	1.0
	Important or continuous	0.8
Peak loads	Light, steady load such as: steam engines, steam turbines, Diesel engines, and multi-cylinder gasoline engines	1.0
	Jerky loads, reciprocating machines such as: normal starting torque squirrel-cage motors, shunt wound D. C. motors, and single cylinder gasoline engines	0.8
	Shock and reversing loads, full voltage start such as: wound rotor (slip ring) motors, synchronous motors	0.6

TABLE 6.—THICKNESS SPECIFICATIONS FOR FLAT LEATHER BELTING (Approved and adopted by American Leather Belting Association)

Medium, single ply, $\frac{11}{64}$ in. average Heavy, single ply, $\frac{13}{64}$ in. average	"All thicknesses in this table are average thickness in inches, and should be determined by measuring 20 coils and dividing this total by the number of coils measured. In rolls of belting containing less than 20 coils, the average thickness should be determined by measuring all the coils in the roll. Allowable tolerances for all thicknesses plus or minus $\frac{1}{64}$th in. from above averages."
Light, double ply, $\frac{18}{64}$ in. average Medium, double ply, $\frac{20}{64}$ inch average Heavy, double ply, $\frac{23}{64}$ inch average	
*Medium, triple ply, $\frac{30}{64}$ inch average *Heavy, triple ply, $\frac{34}{64}$ inch average	Uniformity: No point in single belting shall be more than $\frac{3}{64}$ inch thicker or more than $\frac{3}{64}$ inch thinner than the average thickness. With doubles, the tolerances shall be $\frac{3}{64}$ inch thicker or thinner than the average.

* Triple ply: These are averages for general usage. Most triple ply belts are usually constructed for particular drive conditions. *Tolerances for Single and Double Ply Belts do not apply.*

Texrope Drive

The Texrope drive was originated and developed by Allis-Chalmers Manufacturing Company and consists of a driving and driven sheave, grooved for a multiplicity of belts of trapezoidal cross section, for transmitting power with a reduction in speed from 1:1 up to 7:1 ratio. Power is transmitted by the wedging contact between the Texrope belts and the V-shaped grooves.

Five different cross-section sizes are made endless for various lengths to accommodate various center distances and a range of horse-power capacities as follows:

TABLE 7.—DATA FOR TEXROPE DRIVE

Size of Texrope, Inches	Minimum Recommended Diameter of Small Sheave, Inches	Horse-power at 1,000 F.P.M. Belt Velocity	Horse-power at 4,000 F.P.M. Belt Velocity	Horse-power Range
$\frac{1}{2}$ by $\frac{11}{32}$	4	0.9	2.8	$\frac{1}{2}$ to 5
$\frac{21}{32}$ by $\frac{7}{16}$	6	1.2	4.2	2 to 25
$\frac{7}{8}$ by $\frac{17}{32}$	9	3.0	9.0	15 to 100
$1\frac{1}{4}$ by $\frac{3}{4}$	13	5.5	17.5	50 to 250
$1\frac{1}{2}$ by 1	22	7.5	23.5	100 to 350

Data of table copyrighted 1926, 1928, by Allis-Chalmers Manufacturing Company.

Sheaves somewhat larger than the minimum given are recommended. This drive will run in either direction and with the slack side on either top or bottom, or in a horizontal or vertical position. It requires no lubrication and gives a flexible drive.

BELT FASTENINGS

The best fastening for a belt is the cement splice. It is far beyond any form of lacing, belt hooks, riveting, or any other method of joining together the ends of a belt. The cement joint is easily applied to leather and to rubber belts, but to make a good cement splice in a canvas belt requires more time and apparatus than are usually at hand. Good glue makes a fine cement for leather belts, and fish glue is less affected by moisture than the other. Many of the liquid glues are fish glue treated with acid so as not to gelatinize when cold. A little bichromate of potash added to ordinary hot glue just before it is used will render it insoluble in water. Both lap and wedge joints are used.

Belt Hooks

There are many styles of belt hooks in use, some of the more common kinds being shown in Figs. 1, 2, 3, and 4. Figure 2 is practically a double rivet. Figure 3 is a malleable iron fastening, although similar hooks have been made of pressed steel. Figure 4 is the Blake stud, which has the advantage of not weakening the belt but makes a hump on the outside where the ends turn up. Figure 5 is the Bristol hook of stamped steel which is driven in and the points turned over on the other side. Figure 6 is the Jackson belt lacing and is applied by a hand machine which screws a spiral wire across the ends of a belt. These are then flattened, and a rawhide pin or a heavy soft cord used as a hinge joint between them. These joints are probably equal to 90 per cent of the belt strength.

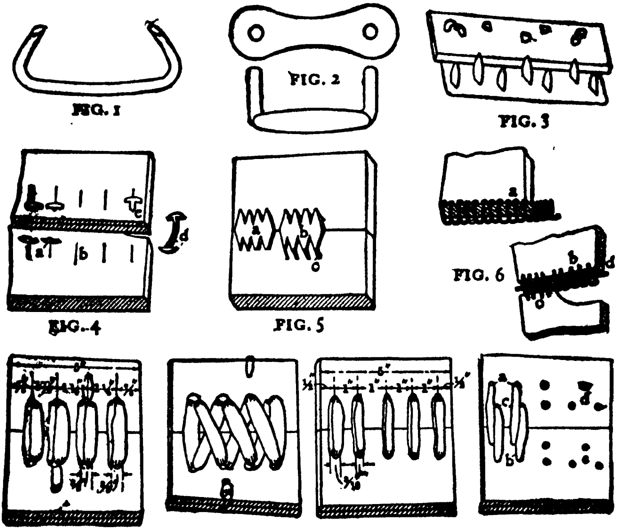


FIG. 1 FIG. 2 FIG. 3 FIG. 4 FIG. 5 FIG. 6

FIG. 7 FIG. 8 FIG. 9 FIG. 10

FIGS. 1 to 10.—Belt Hooks and Lacings

Lacing Belts

Belts fastened by lacing are weakened according to the amount of material punched out in making the holes to receive the lacing. It is preferable to lace with a small lacing put many times through small holes. Such a joint is stronger than a few pieces of wide lacing through a number of large holes. Figures 7 and 9 illustrate two forms of belt lacing, the latter being far preferable to the other. The lacing shown by Fig. 7 is in a double leather belt 5 inches wide. The width makes no difference as the strength is figured in percentage of the total width. There are four holes in this piece of belt, each hole $\frac{3}{8}$ inch in diameter. The aggregate width thus cut out of the belt is $4 \times \frac{3}{8}$ inch $= \frac{12}{8} = 1\frac{1}{2}$ inches. Then $1.5 \div 5 = 0.30$, or 30 per cent of the belt has been cut away—nearly one-third of the total strength. Figure 8 is the other side of Fig. 7.

In Fig. 9 a different method is followed. Instead of there being a few large holes, there are more smaller ones—one-fourth more, in fact. There are five holes, each $\frac{3}{16}$ inch in diameter, making a total of $\frac{15}{16}$ inch or 0.9375 × 5 = 18$\frac{3}{4}$ per cent, leaving 81$\frac{1}{4}$ per cent of the total belt strength against 70 per cent in the belt with large holes. A first-class double leather belt will tear in two under a strain of about 500 pounds to each lace hole, the strain being applied in the holes by means of lacings.

The belt shown by Fig. 9 has 81$\frac{1}{4}$ per cent of 1.875 square inches of section or 1.525 square inches left after cutting out the five holes. This amount is good for 3,000 × 1.875 = 5,625 pounds breaking strain, and as the lacing will tear out under 2,500 pounds, it will be seen that we cannot afford to use lacings if the full power of the leather is to be utilized. This, under a factor of safety of 5, would be 1,125 pounds to the square inch, or 1,125 × 1.525 = 1,715 pounds working strain for the belt or 1,715 ÷ 5 = 343.5 pounds to each lace. This, too, is too much, as it is less than a factor of safety of 2.

The belt to carry 40 pounds working tension to the inch of width must also carry about 40 pounds standing tension, making a strain of 80 pounds to the inch, or 80 × 5 = 400 pounds. This is a better showing, and gives a factor of safety of 2,500 ÷ 400 = 6$\frac{1}{4}$. Still, we are wasting a belt of 5,625 pounds ultimate strength in order to get from it 400 pounds working strain. This means a factor of safety of over 14 in the body of the belt but of only 6$\frac{1}{4}$ at the lacing, which shows the advantage of a cement splice.

Figure 10 shows a method sometimes used to relieve the lace holes of some of the strain. Double rows of holes are punched, as at *a* and *b*, and the lacing distributed among them. As far as helping the strength of the belt is concerned, this does nothing, for all the stress put upon the belt by the lacing at *c* must be carried by the belt section at *a*; therefore, this way of punching holes does not increase the section strength. Neither does staggering the holes as shown at *d* and *e*. The form of hole-punching shown at *a*, *b*, and *c* is desirable for another reason. It distributes the lacing very nicely and does not make such a lump to thump when it passes over the pulleys.

ALIGNING SHAFTING BY A STEEL WIRE

A steel wire is often used for aligning shafting by stretching it parallel with the direction of the shaft and measuring from the shaft to the wire in a horizontal direction. This steel wire can also be used for leveling or aligning in a direction at right angles to the other, by making vertical measurements, if it is stretched under established conditions, and if the sags at the points of measurement are known. The accompanying table gives the sags in inches from a truly level line passing through the points of support of the wire, at successive points beginning 10 feet from the reel and spaced 10 feet apart for a No. 17 Birmingham gage, high-grade piano wire, stretched with a weight of 60 pounds, wound on a reel of a minimum diameter of 3$\frac{1}{2}$ inches, and, for total distances between the reel and point of support of the wire, varying by increments of 10 feet from 40 to 280 feet. Thus a wire of any convenient length, of the kind indicated can be selected, so long as this length is a multiple of 10 feet and between the limits specified. The table gives the sags from a truly level line at points 10 feet apart for its entire length when it is stretched under the conditions designated. These sags being known, direct measurements can be made to level or align a shaft by vertical measurements.

Table 8.—Sags of a Steel Aligning Wire for Shafting

Distance in Feet, from Reel to Point of Support	Distance in Feet, from Reel to Point of Measurement													
	10	20	30	40	50	60	70	80	90	100	110	120	130	140
280	1/4	31/64	11/16	57/64	1 1/16	1 7/32	1 23/64	1 31/64	1 37/64	1 43/64	1 47/64	1 25/32	1 13/16	1 53/64
270	15/64	15/32	43/64	55/64	1 1/64	1 11/64	1 19/64	1 13/32	1 1/2	1 37/64	1 41/64	1 43/64	1 11/16	1 11/16
260	15/64	29/64	41/64	13/16	31/32	1 7/64	1 15/64	1 11/32	1 27/64	1 31/64	1 17/32	1 9/16	1 37/64	1 9/16
250	7/32	27/64	39/64	25/32	15/16	1 1/16	1 11/64	1 9/32	1 11/32	1 13/32	1 7/16	1 15/32	1 15/32	1 7/16
240	7/32	13/32	37/64	47/64	55/64	63/64	1 5/64	1 11/64	1 15/64	1 9/32	1 5/16	1 5/16	1 5/16	1 9/32
230	13/64	3/8	35/64	45/64	13/16	59/64	1 1/64	1 3/32	1 5/32	1 3/16	1 13/64	1 13/64	1 3/16	1 5/32
220	3/16	23/64	33/64	21/32	49/64	7/8	61/64	1 1/64	1 1/16	1 3/32	1 7/64	1 3/32	1 1/16	1 1/64
210	11/64	11/32	1/2	5/8	23/32	13/16	57/64	61/64	63/64	1	1	63/64	61/64	57/64
200	11/64	21/64	29/64	37/64	11/16	49/64	53/64	7/8	29/32	29/32	29/32	7/8	53/64	49/64
190	5/32	19/64	7/16	35/64	41/64	23/32	49/64	13/16	53/64	53/64	13/16	49/64	23/32	41/64
180	5/32	9/32	13/32	33/64	19/32	21/32	45/64	47/64	3/4	47/64	45/64	21/32	19/32	33/64
170	9/64	17/64	3/8	15/32	35/64	39/64	41/64	21/32	21/32	41/64	39/64	35/64	15/32	3/8
160	9/64	1/4	11/32	7/16	1/2	35/64	37/64	19/32	37/64	35/64	1/2	7/16	11/32	1/4
150	9/64	15/64	21/64	13/32	29/64	1/2	33/64	33/64	1/2	29/64	13/32	21/64	13/64	9/64
140	1/8	7/32	5/16	3/8	27/64	7/16	29/64	7/16	27/64	3/8	5/16	7/32	1/8	—
130	7/64	13/64	19/64	23/64	25/64	13/32	13/32	23/64	23/64	19/64	13/64	7/64	—	
120	3/32	11/64	1/4	19/64	5/16	21/64	5/16	19/64	1/4	11/64	3/32	—		
110	3/32	5/32	7/32	17/64	9/32	9/32	17/64	7/32	5/32	3/32	—			
100	3/32	9/64	3/16	7/32	15/64	7/32	3/16	9/64	3/32	—				
90	5/64	1/8	5/32	11/64	11/64	5/32	1/8	5/64	—					
80	1/16	7/64	1/8	9/64	1/8	7/64	1/16	—						
70	3/64	3/32	7/64	7/64	3/32	3/64	—							
60	1/32	1/16	1/16	1/16	1/32	—								
50	1/32	3/64	3/64	1/32	—									
40	1/64	1/32	1/64	—										
30	1/64	1/64	—											

Sag of the Wire in Inches

The method was originally developed for aligning the propeller shafts of vessels, but it is equally serviceable for semiflexible shafting, as factory line shafts.

Speed of Shafting

Line-shaft speed varies with machinery it drives. Probably 250 r.p.m. is an average today, with cases of 400 revolutions per minute, even on 4-inch shafts, and 600 to 700 revolutions per minute on 2-inch shafts for high-speed machinery.

TABLE 9.—HORSE-POWER OF STEEL SHAFTING FOR LINE-SHAFT SERVICE

Shaft Sizes Inches	Revolutions per Minute										Max. Dist. Between Bearings
	100	125	150	175	200	225	250	300	350	400	
1 3/16	2.4	3.1	3.7	4.3	4.9	5.5	6.1	7.3	8.5	9.7	....
1 7/16	4.3	5.3	6.4	7.4	8.5	9.5	10.5	12.7	14.8	16.9	6.8″
1 11/16	6.7	8.4	10.1	11.7	13.4	15.1	16.7	20.1	23.4	26.8	7.2″
1 15/16	10.0	12.5	15.0	17.5	20.0	22.5	25.0	30.0	35.0	40.0	8.2″
2 3/16	14.3	17.8	21.4	24.9	28.5	32.1	35.6	42.7	49.8	57.0	8.9″
2 7/16	19.5	24.4	29.3	34.1	39.0	44.1	48.7	58.5	68.2	78.0	9.6″
2 11/16	26.0	32.5	39.0	43.5	52.0	58.5	65.0	78.0	87.0	104.0	10.2″
2 15/16	33.8	42.2	50.6	59.1	67.5	75.9	84.4	101.3	118.2	135.0	10.8″
3 3/16	43.0	53.6	64.4	75.1	85.8	96.6	107.3	128.7	150.3	171.6	11.4″
3 7/16	53.6	67.0	79.4	93.8	107.2	120.1	134.0	158.8	187.6	214.4	12.0″
3 11/16	65.9	82.4	97.9	115.4	121.8	148.3	164.8	195.7	230.7	243.6	12.5″
3 15/16	80.0	100.0	120.0	140.0	160.0	180.0	200.0	240.0	280.0	320.0	....
4 7/16	113.9	142.4	170.8	199.3	227.8	256.2	284.7	341.7	398.6	455.6	....
4 15/16	156.3	195.3	234.4	273.4	312.5	351.5	390.6	468.7	546.8	625.0	....
5 1/2	207.9	260.0	311.9	363.9	415.9	459.9	520.0	623.9	727.9	830.0	....
6	270.0	337.5	405.0	472.5	540.0	607.5	675.0	810.0	945.0	1080.0	....
6 1/2	343.3	429.0	514.9	600.7	686.5	772.4	858.0	1029.0	1201.0	1372.0	....
7	428.8	535.9	643.1	750.3	847.5	964.7	1071.9	1286.0	1500.0	1695.0	....
8	640.0	800.0	960.0	1126.0	1280.0	1440.0	1600.9	1920.0	2240.0	2560.0	....

This table is based on the formula

$$M = \frac{D^3 \times R}{80}.$$

For heavier work use

$$M = \frac{D^3 \times R}{100}.$$

For head and jack shafts, supported by bearings close to main sheave or pulley so as to prevent transverse strain, the following formula may be used with safety:

$$M = \frac{D^3 \times R}{125}$$

where D = diameter of shaft in inches.
R = number of revolutions per minute.
M = horse-power.

Deflection of shafting from weight of pulleys and pull of belting should not be allowed in excess of 0.001 inch per foot, as this action adds very rapidly to the power cost. If this deflection is at a clutch or sleeve or roller bearing, any of them may be ruined easily and quickly. It can be reduced by using more hangers.

SPEEDS OF PULLEYS AND GEARS

The fact that the circumference of a pulley or gear is always 3.1416 or 3⅐ times the diameter makes it easy to figure speeds by considering only the diameter of both driver and driven pulleys. Belting from one 6-inch pulley to another gives the same speed to both; but if the driving pulley is 16 inches and the driven pulley only 4 inches, it is clear that the small pulley will turn 4 times for every turn of the large pulley. If this is reversed and the small pulley is the driver, the large pulley will make only one turn for every four of the small pulley. The same rule applies to gears if the *pitch diameter*, and not the outside diameter, is taken. The following rules have been arranged for convenience in finding any desired information about pulley or gear speeds.

Having	To Find	Rule
Diameter of Driving Pulley Diameter of Driven Pulley Speed of Driving Pulley	Speed of Driven Pulley	Multiply Diameter of Driving Pulley by its Speed and divide by Diameter of Driven Pulley.
Diameter of Driving Pulley Speed of Driving Pulley Speed of Driven Pulley	Diameter of Driven Pulley	Multiply Diameter of Driving Pulley by its Speed and Divide by Speed of Driven Pulley.
Diameter of Driving Pulley Diameter of Driven Pulley Speed of Driven Pulley	Speed of Driving Pulley	Multiply Diameter of Driven Pulley by its Speed and Divide by Diameter of Driving Pulley.
Diameter of Driven Pulley Speed of Driven Pulley Speed of Driving Pulley	Diameter of Driving Pulley	Multiply Diameter of Driven Pulley by its Speed and Divide by Speed of Driving Pulley.

The rules given above apply equally well to a number of pulley belts together or to a train of gears if *all* the driving and *all* the driven pulley diameters and speeds are grouped together.

TABLES OF CIRCUMFERENTIAL SPEEDS

The tables on pages 980–983, which give circumferential speeds, can be used for obtaining gear and belt speeds and the speed of revolving parts of high-speed motors.

For diameters greater than those given in the tables, the speeds can be obtained by adding together the speeds for two diameters whose sum equals that of the diameter for which we require the speed. For example, to find the speed at a 120-inch diameter and 200 revolution per minute, the following calculation is readily made:

Speed for 100-inch diameter—5,236 feet.
Speed for 20-inch diameter—1,047 feet.
Speed for 120-inch diameter—6,283 feet.

TABLE 10.—CIRCUMFERENTIAL SPEEDS IN FEET PER MINUTE
(*See page* 979)

Diameter in Inches	Revolutions per Minute										
	50	100	150	200	250	300	350	400	450	500	550
1	13	26	39	52	65	79	92	105	118	131	144
2	26	52	79	105	131	157	183	209	236	262	288
3	39	79	118	157	196	236	275	314	353	393	432
4	52	105	157	209	262	314	367	419	471	523	576
5	65	131	196	262	328	393	458	524	589	654	720
6	79	157	236	314	393	471	550	628	707	785	863
7	92	183	275	367	458	550	641	733	825	916	1,008
8	105	209	314	419	524	628	733	838	942	1,047	1,152
9	118	236	353	471	589	707	825	942	1,060	1,178	1,296
10	131	262	393	524	655	785	916	1,047	1,178	1,309	1,440
11	144	288	432	576	720	864	1008	1,152	1,296	1,440	1,584
12	157	314	471	628	785	943	1100	1,257	1,414	1,571	1,728
13	170	340	511	681	851	1021	1191	1,361	1,532	1,701	1,872
14	183	367	550	733	916	1100	1283	1,466	1,649	1,832	2,016
15	196	393	589	785	982	1178	1375	1,571	1,767	1,963	2,160
16	209	419	628	838	1047	1257	1466	1,675	1,885	2,094	2,304
17	223	445	668	890	1113	1335	1558	1.780	2,003	2,225	2,442
18	236	471	707	943	1178	1414	1649	1,885	2,121	2,356	2,592
19	249	497	746	995	1244	1492	1741	1,990	2,238	2,487	2,736
20	262	524	785	1047	1309	1571	1833	2,094	2,356	2,618	2,880
21	275	550	825	1100	1374	1649	1924	2,199	2,474	2,749	3,024
22	288	576	864	1152	1440	1728	2016	2,304	2,592	2,880	3,168
23	301	602	903	1204	1505	1806	2107	2,409	2,710	3,011	3,312
24	314	628	943	1257	1571	1885	2199	2,513	2,827	3,142	3,456
25	327	655	982	1309	1636	1963	2291	2,618	2,945	3,273	3,600
26	340	681	1021	1361	1702	2042	2382	2,723	3,063	3,403	3,744
27	353	707	1060	1414	1767	2121	2474	2,827	3,181	3,534	3,888
28	367	733	1100	1466	1837	2199	2566	2,932	3,299	3,665	4,032
29	380	759	1139	1518	1898	2278	2657	3,037	3,417	3,796	4,176
30	393	785	1178	1571	1964	2356	2749	3,142	3,534	3,927	4.320
31	406	812	1217	1623	2029	2435	2840	3,246	3,652	4,058	4,464
32	419	838	1257	1676	2094	2513	2932	3,351	3,770	4,189	4,608
33	432	864	1296	1728	2160	2592	3024	3,456	3,888	4,320	4,752
34	445	890	1335	1780	2225	2670	3115	3,560	4,006	4,451	4,896
35	458	916	1375	1833	2291	2749	3206	3,665	4,123	4,581	5,040
36	471	943	1414	1885	2356	2827	3299	3,770	4,241	4,712	5,184
37	484	969	1453	1937	2422	2906	3390	3,875	4,359	4,843	5,328
38	497	995	1492	1990	2487	2985	3482	3,979	4,477	4,974	5,472
39	511	1021	1532	2042	2553	3063	3573	4,084	4,595	5,105	5,616
40	524	1047	1571	2094	2618	3142	3665	4,189	4,712	5,236	5,760
41	537	1073	1610	2147	2683	3220	3757	4,294	4,831	5,367	5,904
42	550	1100	1649	2199	2749	3299	3848	4,398	4,948	5,498	6,048
43	563	1126	1689	2251	2814	3377	3940	4,503	5,066	5,629	6,192
44	576	1152	1728	2304	2880	3456	4032	4,608	5,184	5,760	6,336
45	589	1178	1767	2356	2945	3534	4123	4,712	5,301	5,891	6,480
46	602	1204	1806	2408	3011	3613	4215	4,817	5,419	6,021	6,623
47	615	1231	1846	2461	3076	3692	4307	4,922	5,537	6.152	6,768
48	628	1257	1885	2513	3142	3770	4398	5,027	5,655	6,283	6,912
49	641	1283	1924	2566	3207	3849	4490	5,131	5,773	6,414	7,056
50	655	1309	1963	2618	3273	3927	4581	5,236	5,891	6,545	7.200

TABLE 10.—CIRCUMFERENTIAL SPEEDS IN FEET PER MINUTE.—*Continued*

(*See page* 979)

Diameter in Inches	Revolutions per Minute										
	50	100	150	200	250	300	350	400	450	500	550
51	668	1335	2003	2670	3338	4006	4673	5,341	6,008	6,676	7,343
52	681	1361	2042	2723	3403	4084	4764	5,445	6,126	6,807	7,487
53	694	1388	2081	2775	3469	4163	4856	5,550	6,244	6,938	7,631
54	707	1414	2121	2827	3534	4241	4948	5,655	6,362	7,069	7,775
55	720	1440	2160	2880	3600	4320	5040	5,760	6,480	7,199	7,919
56	733	1466	2199	2932	3665	4398	5131	5,864	6,597	7,330	8,063
57	746	1492	2238	2985	3731	4477	5223	5,969	6,715	7,461	8,207
58	759	1518	2278	3037	3796	4555	5314	6,074	6,833	7,592	8,351
59	772	1545	2317	3089	3862	4634	5406	6,178	6,951	7,723	8,495
60	785	1571	2356	3142	3927	4712	5498	6,283	7,069	7,854	8,639
61	799	1597	2395	3194	3992	4791	5589	6,388	7,186	7,985	8,783
62	812	1623	2435	3246	4058	4870	5681	6,493	7,304	8,116	8,927
63	825	1649	2474	3299	4123	4948	5773	6,597	7,422	8,247	9,071
64	838	1676	2513	3351	4189	5027	5864	6,702	7,540	8,378	9,215
65	851	1702	2552	3403	4254	5105	5956	6,807	7,658	8,508	9,359
66	864	1728	2592	3456	4320	5184	6048	6,912	7,775	8,640	9,503
67	877	1754	2631	3508	4385	5262	6139	7,016	7,893	8,770	9,647
68	890	1780	2670	3560	4451	5341	6231	7,121	8,011	8,901	9,791
69	903	1806	2710	3613	4516	5419	6322	7,226	8,129	9,032	9,935
70	916	1833	2749	3665	4581	5498	6414	7,330	8,247	9,163	10,079
71	929	1859	2788	3718	4647	5576	6506	7,435	8,365	9,294	10,223
72	943	1885	2827	3770	4712	5655	6597	7,540	8,482	9,425	10,367
73	956	1911	2867	3822	4778	5733	6689	7,644	8,600	9,556	10,511
74	969	1937	2906	3875	4843	5812	6781	7,749	8,718	9,687	10,655
75	982	1964	2945	3927	4909	5890	6872	7,854	8,836	9,818	10,796
76	995	1990	2985	3979	4974	5969	6964	7,959	8,954	9,948	10,943
77	1008	2016	3024	4032	5040	6048	7056	8,063	9,072	10,079	11,087
78	1021	2042	3063	4084	5105	6126	7147	8,168	9,189	10,210	11,231
79	1034	2068	3102	4136	5171	6205	7239	8,273	9,307	10,341	11,375
80	1047	2094	3142	4189	5236	6283	7330	8,378	9,425	10,472	11,519
81	1060	2121	3181	4241	5301	6362	7422	8,482	9,543	10,603	11,663
82	1073	2147	3220	4294	5367	6440	7514	8,587	9,660	10,734	11,807
83	1087	2173	3259	4346	5432	6519	7605	8,692	9,778	10,865	11,951
84	1100	2199	3299	4398	5498	6597	7697	8,797	9,896	10,996	12,099
85	1113	2225	3338	4451	5563	6676	7789	8,901	10,014	11,127	12,235
86	1126	2251	3377	4503	5629	6754	7880	9,006	10,132	11,257	12,383
87	1139	2278	3417	4555	5694	6833	7972	9,111	10,249	11,388	12,527
88	1152	2304	3456	4607	5760	6912	8063	9,215	10,367	11,519	
89	1161	2330	3495	4660	5825	6990	8155	9,320	10,485	11,650	
90	1178	2356	3534	4712	5891	7069	8247	9,425	10,603	11,780	
91	1191	2382	3574	4765	5956	7147	8338	9,530	10,721	11,912	
92	1204	2408	3613	4817	6021	7226	8430	9,634	10,839	12,043	
93	1217	2435	3652	4870	6087	7304	8522	9,739	10,956	12,174	
94	1231	2461	3692	4922	6152	7383	8613	9,844	11,074	12,305	
95	1244	2487	3731	4974	6217	7461	8704	9,948	11,192	12,436	
96	1257	2513	3770	5027	6283	7540	8796	10,053	11,310	12,566	
97	1270	2539	3809	5079	6349	7618	8888	10,158	11,428		
98	1283	2566	3849	5131	6414	7697	8980	10,263	11,545		
99	1296	2592	3888	5183	6480	7775	9071	10,367	11,663		
100	1309	2618	3927	5236	6545	7854	9163	10,472	11,781		

TABLE 11.—CIRCUMFERENTIAL SPEEDS IN FEET PER MINUTE

Revolutions per Minute

Diameter in Inches			2,400	2,600	2,800	3,000	3,200	3,400	3,600	3,800	4,000	4,400
			1,200	1,300	1,400	1,500	1,600	1,700	1,800	1,900	2,000	2,200
			600	650	700	750	800	850	900	950	1,000	1,100
¼	½	1	157	170	183	196	209	223	236	249	262	288
½	1	2	314	340	367	393	419	445	471	497	524	576
¾	1½	3	471	510	550	589	628	668	707	746	785	863
1	2	4	628	681	733	785	838	890	942	995	1,047	1,152
1¼	2½	5	785	851	916	982	1,047	1,113	1,178	1,244	1,309	1,440
1½	3	6	942	1,021	1,100	1,178	1,257	1,335	1,414	1,492	1,571	1,728
1¾	3½	7	1,100	1,191	1,283	1,375	1,466	1,558	1,649	1,741	1,832	2,016
2	4	8	1,257	1,361	1,466	1,571	1,675	1,780	1,885	1,990	2,094	2,304
2¼	4½	9	1,414	1,531	1,649	1,767	1,885	2,003	2,121	2,238	2,356	2,592
2½	5	10	1,571	1,702	1,833	1,964	2,094	2,225	2,356	2,487	2,618	2,880
2¾	5½	11	1,728	1,872	2,016	2,160	2,304	2,448	2,592	2,736	2,880	3,168
3	6	12	1,885	2,042	2,199	2,356	2,513	2,670	2,827	2,984	3,143	3,456
3¼	6½	13	2,042	2,212	2,382	2,552	2,723	2,893	3,063	3,233	3,403	3,744
3½	7	14	2,199	2,382	2,566	2,749	2,932	3,115	3,299	3,482	3,665	4,032
3¾	7½	15	2,356	2,552	2,749	2,945	3,142	3,338	3,534	3,731	3,927	4,320
4	8	16	2,513	2,723	2,932	3,142	3,351	3,560	3,770	3,979	4,189	4,608
4¼	8½	17	2,670	2,893	3,115	3,338	3,560	3,783	4,006	4,228	4,451	4,896
4½	9	18	2,827	3,063	3,299	3,534	3,770	4,006	4,241	4,477	4,712	5,184
4¾	9½	19	2,985	3,233	3,482	3,731	3,979	4,228	4,477	4,725	4,974	5,472
5	10	20	3,142	3,403	3,665	3,927	4,189	4,451	4,712	4,974	5,236	5,760
5¼	10½	21	3,299	3,573	3,848	4,123	4,398	4,673	4,948	5,223	5,498	6,048
5½	11	22	3,456	3,744	4,032	4,320	4,608	4,896	5,184	5,472	5,760	6,336
5¾	11½	23	3,613	3,914	4,215	4,516	4,817	5,118	5,419	5,720	6.021	6,623

Diameter in Inches												
6	12	24	3,770	4,084	4,398	4,712	5,027	5,341	5,655	5,969	6,283	6,912
6¼	12½	25	3,927	4,254	4,581	4,909	5,236	5,563	5,891	6,218	6,545	7,200
6½	13	26	4,084	4,424	4,764	5,105	5,445	5,786	6,126	6,466	6,807	7,487
6¾	13½	27	4,241	4,594	4,948	5,301	5,655	6,008	6,362	6,715	7,069	7,775
7	14	28	4,398	4,764	5,131	5,498	5,864	6,231	6,597	6,963	7,330	8,063
7¼	14½	29	4,555	4,935	5,314	5,694	6,074	6,453	6,833	7,213	7,592	8,351
7½	15	30	4,712	5,105	5,498	5,890	6,283	6,676	7,069	7,461	7,854	8,639
7¾	15½	31	4,870	5,275	5,681	6,086	6,493	6,988	7,304	7,710	8,116	8,927
8	16	32	5,027	5,445	5,864	6,283	6,702	7,121	7,540	7,959	8,378	9,215
8¼	16½	33	5,184	5,615	6,048	6,479	6,912	7,343	7,775	8,207	8,640	9,503
8½	17	34	5,341	5,785	6,231	6,676	7,121	7,566	8,011	8,456	8,901	9,791
8¾	17½	35	5,498	5,956	6,414	6,872	7,330	7,789	8,247	8,705	9,163	10,079
9	18	36	5,655	6,126	6,597	7,069	7,540	8,011	8,482	8,954	9,425	10,367
9¼	18½	37	5,812	6,296	6,781	7,265	7,749	8,234	8,718	9,202	9,687	10,655
9½	19	38	5,969	6,466	6,964	7,461	7,959	8,456	8,954	9,451	9,948	10,943
9¾	19½	39	6,126	6,637	7,147	7,658	8,168	8,679	9,189	9,700	10,210	
10	20	40	6,283	6,807	7,330	7,854	8,378	8,901	9,425	9,948	10,472	
10¼	20½	41	6,440	6,977	7,514	8,050	8,587	9,124	9,660	10,197	10,734	
10½	21	42	6,597	7,147	7,697	8,247	8,797	9,346	9,896	10,446	10,996	
10¾	21½	43	6,754	7,317	7,880	8,443	9,006	9,569	10,131	10,695		
11	22	44	6,912	7,487	8,063	8,639	9,215	9.791	10,367	10,943		
11¼	22½	45	7,069	7,658	8,247	8,836	9,425	10,014	10,603			
11½	23	46	7,226	7,828	8,430	9,032	9,634	10,236	10,839			
11¾	23½	47	7,383	7,998	8,613	9,228	9,844	10,459				
12	24	48	7,540	8,168	8,797	9,425	10,053	10,681				
12¼	24½	49	7,697	8,338	8,980	9,621	10,263	10,903				
12½	25	50	7,854	8,508	9,163	9,818	10,472					
12¾	25½	51	8,011	8,679	9,346	10,014	10,681					
13	26	52	8,168	8,849	9,529	10,210	10,891					
13¼	26½	53	8,325	9,019	9,712	10,407						
13½	27	54	8,482	9,189	9,896	10,603						
13¾	27½	55	8,639	9,359	10,079	10,799						
14	28	56	8,797	9,530	10,263	10,996						
14¼	28½	57	8,954	9,700	10,446							
14½	29	58	9,111	9,870	10,629							
14¾	29½	59	9,268	10,040	10,812							
15	30	60	9,425	10,210	10,996							

			Revolutions per Minute	
			2,400	2,600
			1,200	1,300
Diameter			600	650
	15¼	30½	61	9,582	10,380
	15½	31	62	9,739	10,551
	15¾	31½	63	9,896	10,721
	16	32	64	10,053	10,891
	16¼	32½	65	10,210	
	16½	33	66	10,367	
	16¾	33½	67	10,524	
	17	34	68	10,681	
	17¼	34½	69	10,839	

To interpolate, we can use the values given for speed for 1- to 10-inch diameters, dividing them by 10, 100, 1,000, etc., to obtain speeds for tenths, hundredths, thousandths, etc. For instance, if the speed for 550 revolutions per minute and 46.186-inch diameter is required, we proceed as follows:

For 46 in. diameter........................speed = 6,623 ft.

For 0.1 in. diameter = $\frac{1}{10}$ of 1-in. diameter speed = 14.4 ft.

For 0.08 in. diameter = $\frac{1}{100}$ of 8-in. diameter speed = 11.5 ft.

For 0.006 in. diameter = $\frac{1}{1000}$ of 6-in. diameter speed = 0.9 ft.

For 46.186 in. diameter........................speed = 6,650 ft.

SELECTING MOTORS FOR MACHINE TOOLS

Alternating-Current Motors

Squirrel-Cage Motors.—These are, in general, similar to shunt-wound direct-current motors, except that no speed regulation is possible. The applications for which they are suitable are the same. These motors have starting torques approximately 150 to 175 per cent of full load with full voltage applied.

The design of modern squirrel-cage motors is such that full-voltage starting is satisfactory without injury; and the only limitation to starting on full voltage is the starting-current limit of the power companies. Above 5 horse-power the starting currents are such that most power companies require reduced-voltage starters. The use of such starters necessarily reduces the starting torque, since this torque varies as the square of the applied voltage. For instance, using the 80 per cent tap of a compensator gives only 64 per cent of the starting torque at full voltage.

Squirrel-Cage, High-Reactance Motors.—These motors are available in two forms—high starting torque and normal starting torque—both having starting currents within the usual power company limits. Because of this feature, they can be used with across-the-line starters, rather than reduced-voltage starters, above 5 horse-power, with a consequent saving in both space and cost.

Motors with high starting torque have a starting torque approximately 250 per cent of full load with full voltage applied. The slip at full load is practically the same as for the standard squirrel-cage motor. They are, therefore, not suitable for punch presses and flywheel machinery unless the machine operates at a large number of work strokes per minute.

Usually the starting torque is higher than is necessary for a machine tool, which, as a rule, starts light. There may be some instances requiring heavy starting torque (such as conveyors or line shafting) for which these motors are admirably adapted.

Motors with normal starting torque have a starting torque at full voltage approximately equivalent to a standard squirrel-cage motor when used on the 80 per cent compensator tap. Likewise, as stated above, the starting currents are low. Consequently, this type of motor is suitable for use on the majority of machine-tool applications.

Squirrel-Cage, High-Resistance-Rotor Motors.—Where heavy starting duty is required, or heavy loads of short duration are encountered, as in flywheel presses, squirrel-cage motors with high-resistance rotors are recommended.

These motors have a higher slip than standard motors, which means that full-load speed will be 10 to 12 per cent below synchronous speed, instead of 4 or 5 per cent as obtained on standard motors. When such motors are used with flywheel machines, the increased slip allows the flywheel to deliver a greater amount of energy before the motor is carrying full load. The use of these motors on such machines is limited to where the work strokes are less than 25 per minute. This is evident from the fact that with more strokes than this the time interval between strokes is insufficient to allow the motor to restore the necessary energy to the flywheel.

Wound-Rotor Motors.—Alternating-current motors with external secondary resistance are used in a manner similar to compound-wound, direct-current motors. They are used where some speed regulation is necessary and, under these conditions, correspond to adjustable varying speed (armature-control) direct-current motors since the current consumed in the resistance to reduce the speed is wasted. These motors are not recommended for speed reductions of more than 50 per cent as their operation is unstable below that. The speed also changes with each change in load. Because of this characteristic, these motors are not suitable for speed control on machine tools since the load varies over a wide range. By inserting a permanent resistance in the secondary, these motors can be used on large presses, etc., and will operate in a manner similar to high-resistance-rotor motors. The use of the external resistor reduces the heating of the motor, since the heat is generated in the resistor away from the motor. With the squirrel-cage motor, the heat is all in the motor itself.

Variable and Multi-Speed Motors.—It is difficult to obtain as wide a speed range with alternating-current motors as with direct current. The nearest approach to this is the commutator-type brush-shifting motor which gives a speed range of 3:1 by shifting brushes. These motors are rated on a constant-torque basis and are not particularly suitable for machine-tool applications, principally because they must be rated at basic speed, which results in a large and expensive machine. Their characteristics are similar to a shunt motor in that the speed, when set, remains practically the same for all loads.

Squirrel-cage motors can be so designed by bringing out extra leads that two, three, or four speeds can be obtained by regrouping the connections. Such motors can be used on tools requiring several speeds provided the motor speeds, with or without a gear box, will be sufficient for the service. Where only two-phase service is available, standard three-phase multi-speed motors and autotransformers are recommended. Where the two phases are symmetrically interconnected, autotransformers cannot be used, and transformers having separate primary and secondary are necessary.

Direct-Current Motors

Shunt-Wound Motors.—These are applicable for drives demanding constant load and where fairly close speed regulation is required. They should also be used where adjustable-speed motors are necessary. In general, they should be used on all machine tools which remove metal by means of a cutting tool or abrasive. They are also applicable to punch presses and flywheel loads where the actual work strokes are 25 per minute or more. Under these conditions the flywheel cannot slow down and then store up enough energy between strokes, and the motor must carry the load. Rotary shears should also be supplied with shunt motors.

Compound-Wound Motors.—These motors should not be used for adjustable-speed service but are suitable for adjustable varying and so-called "constant" speeds. They are applicable to drives demanding high torque peaks, or comparatively high slip, which includes machines which form or bend metal, such as bending rolls, shears (except rotary), presses where the actual work strokes are less than 25 per minute, etc. These motors are also used where heavy starting duty is required, as for instance, cross rail and tool traverse.

Series-Wound Motors.—This type of motor is used where high torque or high slip is demanded and where high speed at light load is not objectionable. Such motors should always be positively connected to their loads.

Adjustable Varying-Speed Motors.—These are motors in which speed regulation is obtained by inserting resistance in series with the armature circuit. Under these conditions the speed reduction at any load depends upon the torque requirements of the motor at that particular load, and the speed may vary over a considerable range for any setting. This is a wasteful method, in that energy must be absorbed in the external resistor. However, such applications as bending rolls require this arrangement.

Another method of speed regulation is by means of "adjustable-speed" motors. In these motors the speed change is obtained by varying the motor field current. This method is more economical than the former and has the further advantage that much wider speed range may be obtained. Furthermore, the speed remains practically constant at any given setting regardless of the load.

Where a very wide speed range is necessary, a combination of both armature and field regulation may be used, but for all speeds below the basic speed the motor is in the adjustable varying-speed class, and the load determines the speed obtained.

Variable-voltage direct-current motor drive offers the most satisfactory means of securing extra-wide speed range operation without the disadvantages of combined armature and field regulation. Current is supplied to the motor from a separately excited variable-voltage direct-current generator driven at constant speed, usually by an alternating-current motor. Variation of field current adjusts the generator output voltage and, thereby, the speed of the direct-current motor, to the value desired. Additional range of speed is secured by variation of the motor field in the usual manner. Standard variable-voltage equipments with 30:1 speed range are used extensively on planer drives; and this scheme is applicable to a variety of machines, where stable operation over an unusually wide speed range is required.

Gear motors provide a low output-speed drive unit which can be coupled direct to the input shaft of a machine, eliminating the use of belt drives or external gearing. The gear parts can be used with any standard type of motor unit, alternating or direct current, constant or variable speed. Use of 900, 1,200, or 1,800 revolutions per minute motors in combination with a wide range of gearing ratios, provides a full choice of output speeds to suit individual machine requirements.

GUIDE TO TYPE OF MOTOR

Reference Letter	Character of Work	Motor	
		Alternating Current	Direct Current
A	When work is fairly steady and constant speed is required with close speed regulation and no excessive starting requirements	Squirrel cage	Shunt wound
B	Speed changes necessary over 3:1 or 4:1 range, with close speed regulation at speed selected	Multi-speed, squirrel cage	Shunt-wound, adjustable speed
C	High slip to prevent excess motor overloads on intermittent peak demands as on flywheel machines[3]	High resistance or wound rotor[1]	Compound-wound, 20 per cent series, 80 per cent shunt
D	Heavy intermittent starting duty as cross rail and tool traverse motors[2]	High resistance	Compound-wound
E	Reversing motors for planers[4]	....	Shunt wound, adjustable speed
F	Ordinary starting duty with speed control. MT motor speed dependent on load, with 50 per cent maximum reduction	Wound rotor or multi-speed squirrel cage	Shunt-wound, adjustable speed
G	Heavy torque for short periods and some speed control during light load such as bending rolls	Crane motor	Compound-wound, 50 per cent shunt, 50 per cent series, crane type
H	Heavy starting torque with close speed regulation	Squirrel cage, high starting torque	Shunt-wound

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[1] With permanent section of resistance in secondary.

[2] Usually rated on 5-minute basis.

[3] Where a machine is equipped with a flywheel for the purpose of producing energy during the work stroke, the motor slip should be sufficient to allow the flywheel to give up the maximum energy between cycles, and slow down just enough to require about 150 per cent load on the motor at the end of the work stroke. In small machines of this type and where the actual work strokes are 25 per minute or more, a relatively low slip is needed, and standard motors can be used (shunt direct current, squirrel cage alternating current). This is because there is not sufficient time, in a fast operating machine, to restore energy to the flywheel between work strokes. Obviously a very light flywheel should be used.

[4] Built with special, low inertia armature for rapid reversal.

Motors for Machine Tools—Types and Sizes

The tables on pages 987–1000 are submitted as an aid in selecting the proper motor. In general, machine tools used to remove metal by cutting tools or abrasives require motors with shunt characteristics, whereas those used to shape metal require the characteristics obtained in compound-wound motors.

The information given as to the size of motor to be used with the different tools is based on average values. For very light or very heavy work these figures may be reduced or increased from the values given. The letters under each group of tools indicate the classes of motors suitable for the application and refer to the table on page 987.

GUIDE TO THE SELECTION OF MOTORS

Type of Motor	Remarks
Shunt-wound motors	When the work is of a fairly steady nature. When a considerable range of speed adjustment is desired When fairly close speed regulation is required.
Compound-wound motors	When there are sudden calls of short duration for heavy loads. When heavy starting duty is required. Where for these duties series motors could not be used on account of excessive light load speeds.
Series motors	When excessive starting torques are required, but only when speed regulation is not important and only when light load speeds do not exceed point of safety.
Squirrel-cage motors	When constant speed is desired and when normal starting duty is suitable.
Squirrel-cage motors, high-resistance rotors	Where heavy starting duty is needed or where high slip is necessary to prevent excess motor overloads or intermittent peak-load demands.
Slip-ring motors	When heavy starting duty is required and speed control is necessary. Maximum speed reduction practicable is 50 per cent. This is obtained by series resistor and speed is dependent on load.
Multi-speed motors	When direct current is not available. When three or four definite speeds, in conjunction with gear changes, will give desired speeds. For machine-tool service two-phase multi-speed motors are not recommended.

TABLE 12.—HORSE-POWER REQUIRED TO REMOVE CAST IRON ON PLANERS

Depth of Cut	Amount of Feed															
	$\frac{1}{32}$	$\frac{1}{16}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{7}{32}$	$\frac{1}{4}$	$\frac{9}{32}$	$\frac{5}{16}$	$\frac{11}{32}$	$\frac{3}{8}$	$\frac{13}{32}$	$\frac{7}{16}$	$\frac{15}{32}$	$\frac{1}{2}$
$\frac{1}{8}$	0.0115	0.0235	0.036	0.047	0.059	0.071	0.082	0.094	0.106	0.118	0.13	0.142	0.153	0.165	0.177	0.189
$\frac{3}{16}$	0.0172	0.0352	0.054	0.070	0.088	0.106	0.123	0.141	0.159	0.177	0.19	0.213	0.230	0.248	0.266	0.283
$\frac{1}{4}$	0.023	0.047	0.073	0.094	0.118	0.142	0.165	0.189	0.213	0.236	0.26	0.284	0.307	0.331	0.355	0.378
$\frac{5}{16}$	0.029	0.058	0.091	0.117	0.147	0.177	0.206	0.236	0.266	0.295	0.325	0.355	0.384	0.414	0.443	0.472
$\frac{3}{8}$	0.035	0.070	0.110	0.141	0.177	0.213	0.248	0.283	0.320	0.354	0.390	0.426	0.461	0.497	0.532	0.567
$\frac{7}{16}$	0.041	0.082	0.128	0.165	0.206	0.248	0.289	0.330	0.373	0.413	0.455	0.497	0.538	0.580	0.621	0.662
$\frac{1}{2}$	0.047	0.094	0.147	0.189	0.236	0.284	0.331	0.378	0.426	0.473	0.520	0.568	0.615	0.663	0.710	0.757
$\frac{9}{16}$	0.055	0.106	0.165	0.212	0.265	0.319	0.372	0.425	0.479	0.532	0.585	0.639	0.691	0.745	0.798	0.851
$\frac{5}{8}$	0.063	0.118	0.184	0.236	0.295	0.355	0.413	0.473	0.532	0.591	0.650	0.710	0.768	0.828	0.887	0.946
$\frac{11}{16}$	0.071	0.130	0.202	0.250	0.325	0.390	0.454	0.520	0.585	0.650	0.715	0.781	0.845	0.911	0.976	1.041
$\frac{3}{4}$	0.080	0.142	0.221	0.284	0.355	0.426	0.496	0.568	0.639	0.709	0.781	0.852	0.922	0.994	1.065	1.136
$\frac{13}{16}$	0.083	0.153	0.239	0.307	0.384	0.461	0.537	0.615	0.692	0.768	0.846	0.923	0.999	1.076	1.153	1.230
$\frac{7}{8}$	0.087	0.165	0.257	0.331	0.414	0.497	0.579	0.662	0.745	0.828	0.911	0.994	1.076	1.159	1.242	1.325
$\frac{15}{16}$	0.090	0.177	0.275	0.354	0.443	0.532	0.620	0.704	0.798	0.887	0.976	1.065	1.153	1.242	1.331	1.420
1	0.094	0.189	0.294	0.378	0.473	0.568	0.662	0.757	0.852	0.947	1.041	1.136	1.231	1.325	1.420	1.515
1 $\frac{1}{16}$	0.100	0.200	0.312	0.401	0.502	0.605	0.703	0.804	0.905	1.006	1.106	1.207	1.307	1.407	1.508	1.609
1 $\frac{1}{8}$	0.106	0.212	0.331	0.425	0.532	0.639	0.745	0.851	0.958	1.065	1.171	1.278	1.384	1.49	1.597	1.704
1 $\frac{3}{16}$	0.112	0.224	0.349	0.449	0.562	0.674	0.786	0.898	1.011	1.124	1.236	1.349	1.461	1.573	1.686	1.798
1 $\frac{1}{4}$	0.118	0.236	0.368	0.473	0.592	0.710	0.827	0.946	1.065	1.183	1.301	1.420	1.538	1.656	1.775	1.893
1 $\frac{5}{16}$	0.125	0.250	0.391	0.502	0.628	0.745	0.868	0.993	1.118	1.241	1.366	1.491	1.614	1.739	1.863	1.987
1 $\frac{3}{8}$	0.133	0.265	0.414	0.532	0.665	0.781	0.910	1.04	1.171	1.30	1.431	1.562	1.691	1.822	1.952	2.082
1 $\frac{7}{16}$	0.140	0.280	0.437	0.561	0.702	0.816	0.951	1.087	1.224	1.360	1.496	1.633	1.768	1.905	2.041	2.177
1 $\frac{1}{2}$	0.148	0.295	0.460	0.591	0.739	0.852	0.993	1.135	1.278	1.420	1.561	1.704	1.845	1.988	2.130	2.272

The Cincinnati Planer Company

To find the size motor necessary to take a given cut, find the figure at the intersection of the depth of cut and feed; multiply this by the cutting speed; the result will be the horse-power for one head in cast iron.

For steel up to 40-point carbon, multiply this result by 2.

For steel above 40-point carbon, multiply this result by 2¼.

Special alloys, 40 to 50 scleroscope, multiply this result by 2½ to 2¾.

Individual Motor versus Group Drives

Selection of power for machine drives should consider several points, such as first cost, cost of power, flexibility or possibility of moving machines, effect on light and cleanliness of shop, probable use of certain machines on overtime work, and general desirability. It is generally admitted that group driving costs less to install and to operate. In one metal stamping shop with 180 machines, the total installation cost of individual motors would have been $48,730. Dividing the shop into 25 groups, and with 58 individual motors on large machines, the first cost was $27,589, according to the Power Transmission Council.

In spite of the cost difference, many shops consider the individual motor drive worth the extra cost on account of the difference in convenience, flexibility, dirt, light, and general appearance.

There are some shops where group driving may be found more desirable than the use of individual motors in both first cost and maintenance, particularly where the machines are comparatively small and run intermittently, as the cost of motors will be less.

Friction load of 2½- to 3-inch shafting, with bearings 8 to 10 feet and running at 150 to 200 revolutions per minute, is about 1 horse-power for every 30 feet of shafting. This includes the friction of countershafts of the machines driven by it.

In group driving it is usually safe to select a motor having a rated capacity of from 25 to 30 per cent of the total power required for the machines in the group if this exceeds the maximum power needed by a single machine of the group.

LEVELING MACHINE BEDS

Leveling machine beds requires the use of a *precision* level. The ordinary level is not satisfactory. A 15-inch Pratt and Whitney, or similar, level with a sensitivity of "10 seconds of arc" is recommended. These have graduations one-tenth inch apart which indicate 0.0005 inch deviation in 1 foot of length.

An accurate parallel bar is also necessary. This is used crosswise of the bed of the machine, the level being placed on this to check the bed in both directions. Nearly all machines are now provided with leveling plates that go between the bed and the foundation and permit adjustment at any time if the foundation has settled or the machine is out of alignment.

CUTTING SPEED OF WOOD-WORKING TOOLS

Circular saw teeth	6,000 to 10,000 feet per minute.
Band saw teeth, hand feed	4,000 feet per minute, up to 6 inches wide.
power feed	5,000 to 8,000 feet per minute, 4 to 8 inches wide.
Planing and molding cutters	5,000 to 8,500 feet per minute.
Shaping and carving cutters	6,000 revolutions per minute.
High speed matcher heads, top and bottom	3,000 revolutions per minute.
Side heads	3,750 revolutions per minute.
Round jointer heads	4,000 revolutions per minute.

MOTORS FOR MACHINE TOOLS

ENGINE LATHES
Motor A or B

Swing, Inches	Horse-power	
	Average	Heavy
12	½	2
14	2	3
16	3	5
18	5	7½
20 to 22	7½	10
24 to 27	10	15
30	15	20
32 to 36	20	25
38 to 42	20	25
48 to 54	25	30

AXLE LATHES
Motor A or B

Type of Lathe	Horse-power
13-inch center drive....	25
14-inch end drive.......	25

WHEEL LATHES
Motor F

Size, Inches	Motor D	
	Horse-power	For Tail Stock, Horse-power
48	15 to 20	5
51 to 60	15 to 20	5
79 to 84	25 to 30	5
90	30 to 50	10
100	40 to 50	10

BORING AND TURNING MILLS
Motor A or B

Size	Horse-power	
	Main	Cross Rail
36 to 44 inches	7½ to 10	
50 to 53 inches	7½ to 10	
60 inches	15	3
72 inches	15 to 20	3
84 inches	15 to 20	5
96 inches	20 to 25	5
10 feet	20 to 30	7½
12 feet	25 to 40	7½
14 feet	30 to 40	7½
16 feet	40 to 50	10
20 to 25 feet	50	15
30 feet	50 to 60	15

HORIZONTAL BORING, DRILLING AND MILLING MACHINES
Motor A or B

Size of Spindle, Inches	Horse-power for Single Spindle
2	5
3½	5 to 7½
4½	7½ to 10
5½	10 to 15

CYLINDER BORING MACHINE
Motor A or B

Diameter of Spindle, Inches	Maximum Boring Diameter, Inches	Horse-power
4	20	7½
6	30	10
8	40	15

RECIPROCATING TABLE PLANERS
Motor A, B or E[1]

Width	Type of Duty, Horse-power		
	Ordinary	Light	Heavy
	General Purpose	Lightly Constructed Planers Average Cuts	Heavy Planers, Heavy Cuts
36 inches.	10	10	15
48 inches.	15	10	20
56 inches	15	15	20
60 inches.	20	15	25
72 inches.	25	20	35
84 inches.	25	25	35
96 inches.	35	25	50
10 feet ..	35	35	75
12 feet...	50	50	75
16 feet. .	75	50	100

[1] For reversing motor only.

HEAVY FORGE PLANERS
Motor E

Size, Feet	Horse-power	
	Platen	Cross Rail
12 by 10	60	10
14 by 12	75	10

ROTARY PLANERS
Motor A or B

Diameter of Cutter, Inches	Horse-power
24 to 26	5
36 to 42	10
48 to 54	15
72	25
84	30
96 to 100	40

SHAPERS
Motor A or B

Stroke, Inches	Horse-power
12–16–18	2 to 5
20	3 to 7½
24–28	5 to 10

CRANK SLOTTERS
Motor A or E

Size, Inches	Horse-power
6	2 to 3
8	3
10 to 12	5 to 7½
15	7½ to 10
18	7½ to 10
20 to 24	10 to 15
24 to 30	10 to 20

SLOTTING AND KEYSEATING MACHINE
Motor A or E

Stroke, Inches	Horse-power	Stroke. Inches	Horse-power
6 to 8	3 to 5	18	7½ to 10
10	5	20 to 30	10 to 15
14	5 to 7½	......	10 to 15

PLAIN MILLING MACHINES
Motor A or B

Feed, Inches		Horse-power
Table	Cross	
22	8	3 to 5
28	10	5
34	12	7½ to 10
42	14	10 to 15
50	14	15 to 20

Universal Milling Machines
Motor A or B

Feed, Inches		Horsepower
Table	Cross	
22	8	1½ to 5
28	10	3 to 5
34	12	5 to 7½
42	14	10 to 15

Vertical Milling Machines
Motor A or B

Height under Spindle, Inches	Horse-power
12	
14	2 to 3
18	3 to 5
20	5 to 7½
22	10 to 15
24	20

Horizontal Slab Millers
Motor A or B

Width between Housings, Inches	Horse-power
20	10 to 15
30	20 to 40
36	40 to 50
48	40 to 60
72	50 to 75
90	60 to 75

Continuous Milling Machines
Motor A or B

Diameter Table, Inches	Horse-power
24 to 30	7½
36 to 48	7½
	10 to 15

Cylindrical Grinding Machine—Landis
Motor A or B

	Motor A	Motor B
Diam. of work	6 inches	10 inches
Work drive...	⅓ H.P.	1 H.P.
Pump drive...	1½ H.P.	2 H.P.
Spindle drive.	5 H.P.	10–15 H.P.

Grinding Wheels, Double End
Motor A

Size of Wheel, Inches	Horse-power
8 by 1	½
12 by 2	3
18 by 3	5 to 7½
24 by 4	7½ to 10
30 by 4	15 to 20

Miscellaneous Grinders
Motor A

Type of Machine	Horse-power
Wet tool grinder......	2 to 3
Flexible swinging machine polish....	3
Angle cock grinder....	3
Piston rod grinder....	3
Twist-drill grinder....	2
Automatic tool grinder............	3 to 5

Buffing Lathes
Motor A

Size of Wheel, Inches	Horse-power
8 by 1½	1 to 2
10	1 to 2
14	3 to 5

UPRIGHT DRILLS
Motor A or B

Size, Inches	Horse-power
12 to 22	1
24 to 28	2
36 to 40	5

RADIAL DRILLS
Motor A or B

Arm in Feet	Horse-power
2½ to 3	3
5	7½ to 10
8 to 10	25 to 40

SENSITIVE DRILLS
Motor A or B

½-inch drill ..... ½ horse-power
¾-inch drill ..... ¾ horse-power

GEAR CUTTERS
Motor A or B

Size, Inches	Horse-power
24 by 6	2
48 by 10	3 to 5
60 by 12	5 to 7½
72 by 14	7½ to 10
64 by 20	10 to 15

COLD CUT-OFF SAWS
Motor A or B

Diameter of Saw, Inches	Horse-power
20	5
26	10
32	15
36	20
42	25
48	25
56	30
62	30
72	40
90	50

BOLT AND NUT MACHINES
Motor A or B

Size, Inches	Horse-power		
	Single	Double	Triple
¼ to ½	1	1½	
¼ to 1	2	3	5
½ to 1½	2	3	5
½ to 2	3	5	7½
¾ to 2½	3	5	
1 to 3	5		
1½ to 4	7½	10	

PIPE THREADING AND CUTTING OFF MACHINES
Motor A, B, or C

Size Pipe, Inches	Horse-power
¼ to 3	3
1 to 6	7½
2½ to 8	10
4 to 12	15
8 to 18	20
10 to 20	25

BULLDOZERS
Motor C

Width, Inches	Head Movement, Inches	Horse-power
29	14	5
34	16	7½
39	16	10
45	18	15
63	20	20

HAMMERS
Motor C

Size, Pound	Horse-power
15 to 75	½ to 5
100 to 200	5 to 7½

Drop hammers require approximately 1 horse-power for every 100-pounds weight of hammer.

HYDROSTATIC WHEEL PRESSES
Motor A

Size, Tons	Horse-power for Pump
100	5
200 to 300	7½
	7½
400	15
600	10

BENDING AND STRAIGHTENING ROLLS
Motor G

Width, Feet	Thickness, Inches	Horse-power
4 to 6	⅜ to 5/16	5
6	¾	15
10	1⅛ to 1½	40 to 50
24	1	50

PUNCHES AND SHEARS
Motor C

Punch Size of Hole, Inches	Shear Size of Bar, Inches	Horse-power
⅜ by ¼	2¾ by ¼	1
⅝ by ⅝	3 by ⅝	2 to 3
¾ by ¾	....	3 to 5
1 by ½	....	5
1 by 1	6 by ⅞	7½
1¾ by 1	8 by 1⅛	10 to 15
2¼ by 1⅛	9 by 1¼	15
2½ by 1½	11 by 1½	20
3 by 2	10 by 2½	25

MOTORS USUALLY EMPLOYED FOR CRANES AND HOISTS

Hoist

Capacity, Tons	Speed, Feet per Minute	Horse-power
5	25	15
	50	25
10	30	25
	40	40
15	20	25
20	15	25
25	10	25
	15	40
30	14	40
5 aux.	50	25
10 aux.	25	25
50	10	40
5 aux.	50	25
10 aux.	25	25

Bridge

Capacity, Tons	Span, Feet	Horse-power	Trolley Horse-power
5	60	20	3
10	80	25	3
15	80	25	5
20	80	25	5
25	80	25	5
30	80	40	7½
35	80	40	7½–10

POWER REQUIRED FOR PLANING-MILL EQUIPMENT

BAND SAWS

Diam. Wheel, Inches	Max. Width of Saw	Horse-power
30	½	2
34	½	3
36–38	½–1½	3–5
40–42	½–1½	4–7½

CIRCULAR RIP SAWS

Diam. Saw	No. of Saws	Horse-power
14	1	5
16	1	7½
24	1	10
36	1	15

SURFACERS

Size, Inches	No. Heads	Horse power	
30 × 6	1–2	15–20	Heavy Work
24 × 6	1–2	15–20	
30 × 8	2	30	
26 × 8	2	30	
24 × 6	1	5– 7½	Light Work
16 × 6	1	5– 7½	
24 × 8	1	10	
30 × 8	1	10	

PLANERS, MATCHERS AND FLOORING MACHINES

Size, Inches	Heads	Horse-power
9 × 8	4–5	30
19 × 8	4–5	30
24 × 8	4–5	40

OUTSIDE MOULDERS

Capacity, Inches	No. Heads	Horse-power
4 × 4	1–2	5
4 × 4	3–4	7½
6 × 4	1–2	5
6 × 4	3–4	7½
8 × 4	4	10
10 × 4	4	15
12 × 5	4	20

CUT-OFF SAWS

Diam. Saw	No. of Saws	Horse-power
12–14	1	3– 5
16	1	5– 7½
16	2	7½–10
30	1	10–15

INSIDE MOULDERS

Inches		Horse-power
8 × 4	4	15
10 × 4	4	15
10 × 6	4–5	20–30

JOINTERS

Inches	Horse-power
8–12	2
16–24	3
30–36	5

TENONING MACHINES

Inches	No. Heads	Horse-power
5½ × 14	1	3– 5
5½ × 15	2	5
23 × 9	2	7½
54 × 4½	4–8	10 –15
78 × 4½	4–8	10 –15
Gainers		7½–10–15

BELT SANDERS

Width of Belt, Inches	Horse-power
6–14	2–3
18	5

DRUM SANDERS

Length of Drum, Inches	Horse-power
30	7½
36	10
42–48	15
54–60	20
72–84	30

Power Required for Punching and Shearing

Experiments tend to show that with steel plates of 60,000 pounds tensile strength, the metal is all sheared when the punch has passed one-half through the plate. The following formula by L. R. Pomeroy takes this into account and also allows the motor an efficiency of 80 per cent and the punching machine 75 per cent.

$$P = \frac{T^2 \times D \times N}{3.78}$$

where T = full thickness of plate.
D = diameter of hole punched.
N = number of holes punched per minute.
P = horse-power required to drive machine.

Taking a ½-inch hole in a ½-inch plate, the power required to punch 30 per minute would be

$$\frac{\frac{1}{4} \times \frac{1}{2} \times 30}{37.8} = \frac{3.75}{3.78} \text{ or about 1 horse-power.}$$

Pressure required for shearing = length of cut × thickness in inches × shearing strength of material. Dies with "shear" reduce this one-third to one-half.

Power Required to Remove Metal

Two factors enter into the problem of power for driving machines'

$$\text{Time factor} = \frac{\text{actual cutting time}}{\text{total time to complete operation}}.$$

$$\text{Load factor} = \frac{\text{average daily load}}{\text{full-load rating of motor}}.$$

The average load factor for motors driving lathes is from 10 to 25 per cent. On some special machines, such as driving-wheel and car-wheel lathes, the cuts are all heavy, increasing the average load factor to from 30 to 40 per cent.

For extension boring mills, 5-horse-power motors are used to move the housings on from 10- to 16-feet mills; 7½ horse-power, for from 14- to 20-feet mills; and 10 horse-power, for from 16- to 24-feet mills. The load factor of the driving motor on boring mills averages from 10 to 25 per cent.

The load factor of motor-driven drills is about 40 per cent when the larger drills applicable thereto are used. If the smaller drills are used, the load factor averages 25 per cent and lower.

For the average milling operations the load factor averages from 10 to 25 per cent. On slab milling machines, where large quantities of metal are removed, it will average from 30 to 40 per cent.

The work on this class of machinery is usually light and much time is required in making adjustments. Hence the load factor is rarely higher than 20 per cent.

On planers the load factor averages between 15 and 20 per cent. With 10 horse-power or under belt-shifting drives probably give better results than direct-connected reversing motors.

The work done on shapers is of a varying character. With light work the load factor will not exceed from 15 to 20 per cent; with heavy work, the load factor will be as high as 40 per cent.

The conditions with slotters are similar to those on shapers.

HORSE-POWER TO DRIVE MACHINES

Extensive experiments by L. R. Pomeroy showed that the horse-power required equals the feed per revolution or stroke × depth of cut in inches × cutting speed in feet per minute × 12 × number of tools cutting × a constant which depends on the material. This checks up fairly well with actual motor tests. The constants given are:

Cast iron	0.35 to 0.5
Wrought iron or soft steel	0.45 to 0.7
Locomotive driving wheel tires	0.70 to 1.00
Very hard steel	1.00 to 1.10

Power Used in Drilling

Drilling tests by Prof. O. W. Boston gave the following results as to power consumed on S.A.E. Steel No. 6150:

Drill Diam.	R. P. M. of Drill	Feed per Rev.	Thrust in Pounds	H. P.
½	444	0.009	752	1.19
⅝	368	0.011	838	1.57
¾	300	0.012	1269	1.97
1	228	0.013	1862	2.72
1¼	175	0.015	2430	3.71
1½	149	0.015	3000	4.08

Tests on cast iron were as follows:

Drill Diam.	R. P. M. of Drill	Feed per Rev.	Thrust in Pounds	H. P.
½	446	0.009	530	0.54
⅝	364	0.011	645	0.71
¾	300	0.012	803	0.90
1	230	0.013	1088	1.23
1¼	179	0.015	1403	1.60
1½	153	0.015	1700	1.94

Handling this in another way, Charles Robbins of the Westinghouse Electric & Manufacturing Co. gives:

H.P. = cubic inches removed per minute × a constant.

These constants, for average conditions with average tools, are:

Brass and similar alloys	**0.2 to 0.3**
Cast iron	**0.3 to 0.5**
Wrought iron	**0.6**
Mild steel (0.30 to 0.40 carbon)	**0.6**
Hard steel (0.50 carbon)	**1.00 to 1.25**
Very hard tire steel	**1.50**

A brief summary of the studies by Mr. Robbins gives interesting data on various machines, including the following data:

	Time Factor	Load Factor
Vertical boring machine	44%	27%
Radial drilling machine	41	10
Portable milling machine	54	55
Portable slotting machine	50	12
Planers	55	

L. R. Pomeroy also gave a method of determining the horse-power required by the belt used to drive the machine. The formula is:

H.P. = thickness of belt in inches × width of belt in inches × diameter of pulley in inches × revolutions per minute × constant for kind of belt.

These constants are:

Leather belt	0.0062 to 0.0098
Cotton belt	0.0036 to 0.0068
Rubber belt	0.0050 to 0.0082

SPEED FOR WOOD TURNING

A good average surface or cutting speed for a wood-turning lathe is from 1,000 to 1,500 feet per minute. Where work does not exceed 1 inch in diameter, the speed may be 3,000 revolutions per minute; for 2-inch stock, 2,500; for 3-inch stock, 2,000, or a little less; and for larger stock it is reduced in proportion.

COOLING HOT BEARINGS

A hotbox can be cooled by pouring sulphur on the bearing. It melts at 220°F. and puts a smooth surface on both journals and bearings. It fills the oil groove but can be dissolved with benzene if machine cannot be stopped. Either stick or flowers of sulphur will do. Graphite is also good but cannot be used where the color is objectionable as in flour mills or other white stock.

HIGH-CYCLE MOTORS

High-cycle motors for portable tools use alternating three-phase current of 180 cycles with 220 volts. The outstanding advantage is the maintenance of speed and power under load, which increases the productive capacity of the tool it drives. As there are no wire windings, soldered joints, commutation, or brushes, maintenance cost and loss of time are greatly reduced.

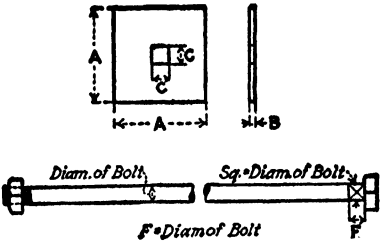
HINTS AS TO PROPER MOTOR SELECTION FOR VARIOUS MACHINES

The following table is suggested by the General Electric Company as an aid in selecting the proper motor winding. For convenience, the table is divided into two parts. In general, machine tools used to remove metal by cutting tools or abrasives require shunt motors, and those used to shape metal require compound direct-current motors.

Motors for Machine Tools							
Tool	Direct Current		Alternating Current				Remarks
	Shunt	Comp.	Squirrel-Cage Rotor	Squirrel-Cage High-resistance Rotor	Multi-speed Squirrel Cage	Slip-ring Induction Motor	
Bolt cutter	×		×				From this table it will be seen that, with the exception of planers (reversing motor), motors may be either direct-current shunt-wound or alternating-current squirrel-cage type. Where the machine is of the constant-speed type, either alternating-current or direct-current motor may be used, depending upon the current supply. Where adjustable speed is required, the machine must be equipped with necessary gear changes, if alternating-current motor is employed. Multi-speed motors can be used with less complicated speed boxes.
Boring machines	×		×		×		
Boring mills	×		×		×		
Boring bars	×		×		×		
Centering machines	×		×				
Chucking machines	×		×				
Boring, milling and drilling machines	×		×		×		
Drill, radial	×		×		×		
Drill press	×		×		×		
Grinders	×		×				
Gear cutters	×		×		×		
Key seaters	×		×				
Lathes	×		×		×		
Milling machines	×		×				
Pipe cutters	×		×				

Planers—rotary	X		X				When speed adjustment is desired, use direct-current adjustable-speed motor, except where multi-speed alternating-current motor is wanted, and then only in conformity with paragraph on "multi-speed motors."
Planers—reversing motor	X						
Saw—small circular	X		X				
Screw machine	X		X				
Shapers	X		X				
Slotters	X		X				
Tappers	X		X				
Bulldozers		X		X	X	X	Squirrel-cage motors of the high-resistance rotor type approach the characteristics of direct-current compound-wound motors in that they provide the necessary slip, *i.e.*, slow down under load. This type of motor in capacities over 25 horse-power is not generally recommended because of the heat produced in the rotor. A wound rotor motor with external resistor to produce the desired slip is preferable.
Bending rolls		X				X	
Hammers—drop		X		X		X	
Hammers—helve	*	X	*	X			
Lathe carriages—cross-rail		X		X			
Heading, upsetting and forging machines		X		X		X	
Punch press	*	X	*	X		X	
Planers—belt reversing		X	X				
Saw—friction		X	X	X			
Shears—Flywheel type	*	X	X	X			
Shears—Rotary type	X		X				
Swaging	*	X	*	X			
Tumbling barrels or mills		X	X				

*Where a machine is equipped with a flywheel for the purpose of producing energy during the work stroke, the motor slip should be sufficient to allow the flywheel to give up the maximum energy between cycles, and slow down just enough to require about full load on the motor at the end of the work stroke. In small machines of this type and where the actual work strokes are 35 per minute or more, a relatively low slip is needed, and standard motors can be used (shunt direct-current—squirrel-cage alternating-current). This is because there is not sufficient time, in a fast operating machine, to restore energy to the flywheel between work strokes. Obviously, a very light flywheel should be used.



FOUNDATION BOLTS AND WASHERS

TABLE 13.—FOUNDATION BOLTS AND WASHERS USED AT THE CHESTER, PA., PLANT OF THE AMERICAN STEEL FOUNDRIES

Diam. of Bolt in Inches	*A* in Inches	*B* in Inches	*C* in Inches	Weight of Washer, Pounds	Weight of Bolt 1 Foot Long Including Head	Weight of Square Nut in Pounds	Weight of Square Head in Pounds	Weight of Each Additional Inch of Bolt, Pounds
½	5	⅜	⅝	2.61	0.76	0.085	0.094	0.056
⅝	5	⅜	¾	2.59	1.21	0.153	0.168	0.087
¾	6	⅜	⅞	3.74	1.77	0.250	0.273	0.125
⅞	6	⅜	1	3.71	2.46	0.381	0.416	0.170
1	6	⅜	1⅛	3.69	3.27	0.552	0.598	0.223
1⅛	6	⅜	1¼	3.65	4.21	0.769	0.834	0.282
1¼	6	⅜	1⅜	3.62	5.29	1.03	1.12	0.348
1⅜	6	⅜	1½	3.58	6.51	1.35	1.46	0.421
1½	8	½	1⅝	8.68	7.87	1.72	1.87	0.501
1⅝	8	½	1¾	8.62	9.40	2.17	2.35	0.588
1¾	8	½	1⅞	8.56	11.09	2.69	2.91	0.682
1⅞	8	½	2	8.49	12.93	3.26	3.54	0.782
2	12	¾	2⅛	29.61	14.95	3.94	4.27	0.890
2¼	12	¾	2⅜	29.37	19.72	5.51	6.00	1.127
2½	12	¾	2⅝	29.10	24.84	7.49	8.15	1.391

The table gives the necessary data from which the weights of bolts from ½ to 2½ inches in diameter can be computed. The weights of the nuts and the sizes and weights of the washers are also given.

SECTION XXI

METALS AND OTHER MATERIALS

HEAT-TREATMENT OF STEEL

The theory of the heat-treatment of steel rests upon the influence which the rate of cooling has on certain molecular changes in structure occurring at different temperatures in the solid state. These changes are of two classes, critical and progressive; the former occur periodically between certain narrow temperature limits, while the latter proceed gradually with the rise in temperature, each change producing alterations in the physical characteristics. By controlling the rate of cooling, these changes can be given a permanent set, and the physical characteristics can thus be made different from those in the metal in its normal state.

The highest temperature to which it is safe to submit a steel for heat-treating is governed by the chemical composition of the steel. Very low carbon steel may be heated to about 1650°F., but high-carbon tool steels will harden at a lower temperature. The steelmaker's advice as to the best hardening temperature should be given careful consideration. From 1400 to 1450°F. is usually sufficient. Some of the high-grade alloy steels may safely be raised to 1750°F., and the high-speed steels may be raised to just below the melting point, usually from 2200 to 2400°F. It is necessary to raise the metal to these points so that the active cooling process will have the desired effect of checking the crystallization of the structure.

TERMS RELATING TO HEAT-TREATMENT OPERATIONS

As Adopted by a Joint Committee of the A.S.T.M., S.A.E., and A.S.S.T.

Heat-Treatment.—An operation, or combination of operations, involving the heating and cooling of a metal or an alloy in the solid state. (Heating and cooling for the sole purpose of mechanical working are excluded from the meaning of this definition.)

Quenching.—Immersing to cool.

Hardening.—Heating and quenching certain iron-base alloys from a temperature either within or above the critical-temperature range.

Annealing.—Annealing is a heating and cooling operation of a material in the solid state. In annealing, the temperature of the operation and the rate of cooling depend upon the material being heat-treated and the purpose of the treatment. (Usually relatively slow cooling is implied.)

Certain specific heat-treatments coming under the comprehensive term "annealing" are:

Full Annealing.—Heating iron-base alloys above the critical-temperature range, holding above that range for a proper period of time, followed by slow cooling through the range. The annealing temperature is generally about 100°F. (55°C.) above the upper limit of the critical-temperature range, and the time of holding is usually not less than 1 hour for each inch of section of the heaviest objects being treated. The objects being treated are ordinarily allowed to cool slowly in the furnace. They may, however, be removed from the furnace and cooled in some medium which will prolong the time of cooling as compared to unrestricted cooling in the air.

Process Annealing.—Heating iron-base alloys to a temperature below or close to the lower limit of the critical range followed by cooling as desired This heat-treatment is commonly applied in the sheet and wire industries, and the temperatures generally used are from 1020 to 1200°F. (550 to 650°C.).

Normalizing.—Heating iron-base alloys above the critical-temperature range, followed by cooling to below that range in still air at ordinary temperature.

Patenting.—Heating iron-base alloys above the critical-temperature range followed by cooling to below that range in molten lead maintained at a temperature of about 700°F. (365°C.). Usually applied in the wire industry either as a finishing treatment or, especially in the case of eutectoid steel, as a treatment previous to further wire drawing. Its purpose is to produce a sorbitic structure.

Spheroidizing.—Prolonged heating of iron-base alloys at a temperature in the neighborhood of, but generally slightly below, the critical-temperature range, usually followed by relatively slow cooling.

Tempering (also termed **Drawing**).—Reheating, after hardening to some temperature below the critical-temperature range, followed by any rate of cooling.

Malleablizing.—Annealing operation with slow cooling whereby combined carbon in white cast iron is transformed to temper carbon, and in some cases the carbon is entirely removed from the iron.

Graphitizing.—Annealing of cast iron whereby some or all of the combined carbon is transformed to free or uncombined carbon.

Carburizing (Cementation).—Adding carbon to iron-base alloys by heating the metal below its melting point in contact with carbonaceous material. ("Carbonizing" is an undesirable term.)

Case Hardening.—Carburizing and subsequent hardening by suitable heat-treatment all or part of the surface portions of a piece of iron-base alloy.

Case.—That portion of a carburized iron-base alloy article in which the carbon content has been substantially increased.

Core.—That portion of a carburized iron-base alloy article in which the carbon content has not been substantially increased. (The terms "case" and "core" refer to both case hardening and carburizing.)

Cyaniding.—Surface hardening of an iron-base alloy article or portion of it by heating at a suitable temperature in contact with a cyanide salt, followed by quenching.

Methods of Heating

Furnaces using solid fuel, such as coal, coke, charcoal, etc., are the most numerous and have been used the longest. These furnaces consist of a grate to place the fuel on, an arch to reflect the heat, and a plate to put the pieces on. The plate should be so arranged that the flames will not strike the pieces to be heated, and for that reason some use cast-iron or clay retorts which are open on the side toward the doors of the furnace.

The use of both gas and oil furnaces is increasing, owing to the ease with which the fire is handled and the cleanliness as compared with a coal, coke, or charcoal fire. The electric furnace is also growing in use, the ease with which heat can be controlled being an important factor.

Heating in Liquids

Furnaces using liquid for heating have a receptacle, such as a pot or crucible, to hold the liquid, which is heated by coal, oil, gas, or other means; the liquid is kept at the highest temperature to which the piece should be heated. The piece should be preheated slowly in an ordinary furnace to about 800 degrees, after which it should be immersed in the liquid bath and kept there long enough to attain the temperature of the bath and then removed to be annealed or hardened.

The bath usually consists of lead, although antimony, cyanate of potassium, chloride of barium, a mixture of chloride of barium and chloride of potassium in the proportion of 3:2, mercury, common salt, and metallic salts have been successfully used.

This method gives good results, as no portion of the piece to be treated can reach a temperature above that of the liquid bath; a pyrometer attachment will indicate exactly when the piece has arrived at that temperature. The bath can be maintained easily at the proper temperature, and the entire process is under perfect control.

When lead is used it is liable to stick to the steel, unless it is pure, and retard the cooling of the spots where it adheres. Impurities, such as sulphur, are liable to be absorbed by the steel and thus affect its chemical composition. With high temperatures, lead and cyanate of potassium throw off poisonous vapors which make them prohibitive, and even at comparatively low temperatures these vapors are detrimental to the health of the workmen in the hardening room unless great care is used in exhausting the fumes by mechanical means. The metallic salts, however, do not give off these poisonous vapors and are much better to use for this purpose, but many times the fumes are unbearable.

Gas and Oil as Fuel

Furnaces using gaseous fuel are very numerous and are so constructed that they can use either natural gas, artificial gas, or producer gas. They are very easy to regulate and, if well built, are capable of maintaining a constant temperature within a wide range. In first cost this style of furnace is greater than that of the solid fuel furnaces, but where natural or producer gas is used, the cost of operating is so much less that the saving soon pays for the cost of installation.

Oil-fired furnaces are also being used in large numbers and electric furnaces are to be found even in small shops. Accurate temperature control makes them both desirable.

Annealing

The appliances for annealing are as numerous as the baths for quenching, and where a few years ago the ashes from the forge were all that were considered necessary for properly annealing a piece of steel, today many special preparations are being manufactured and sold for this purpose.

The more common materials used for annealing are powdered charcoal, charred bone, charred leather, slaked lime, sawdust, sand, fire clay, magnesia or refractory earth. The piece to be annealed is usually packed in a metal box, using some of these materials or combinations of them for the packing; the whole is then heated in a furnace to the proper temperature and set aside, with the cover left on, to cool gradually to the atmospheric temperature.

Although cast-iron boxes are most common, there is an increasing use of such alloys as nichrome (nickel and chromium) on account of their longer life under continual heating and cooling.

For certain grades of steel these materials give good results; but for all kinds of steels and for all grades of annealing, the slow-cooling furnace perhaps gives the best satisfaction, as the temperature can be easily raised to the right point, kept there as long as necessary, and then regulated to cool down as slowly as is desired. The gas, oil, or electric furnaces are the easiest to handle and regulate. For annealing tool steel, about 1400°F. is usually sufficient.

Annealing is now used to designate heating for the purpose of softening. To remove stresses in steel, it is heated above the calescent point. This is called "normalizing."

The Hardening Bath

In hardening steels the influence of the bath depends upon its temperature, its mass, and its nature; or, to express this in another way, upon its specific heat, its conductivity, its volatility, and its viscosity. With other things equal, the lower the temperature of the bath, the quicker the metal will cool and the more pronounced will be the hardening effect. Thus, water at 60 degrees will make steel harder than water at 150 degrees, and when the bath is in constant use the first piece quenched will be harder than the tenth or twentieth, owing to the rise in temperature of the bath. Therefore, if uniform results are to be obtained in using a water bath, it must either be of a very large volume or kept cool by some mechanical means. In other words, the bath must be maintained at a constant temperature.

The mass of the bath can be made large, so no great rise in temperature is made by the continuous cooling of pieces, or it can be made small and its rise in temperature used for hardening tools that are to remain fairly soft, as, if this temperature is properly regulated, the tool will not have to be reheated and tempered later, and cracks and fissures are not so liable to occur.

Another way of arriving at the same results would be to use the double bath for quenching, that is, to have one bath of some product similar to salt which fuses at 575°F. Quench the piece in that until it has reached its temperature, after which it can be quenched in a cold bath or cooled in the air.

GRADES AND USES OF CARBON STEELS

Carbon steel is used for more different purposes than any other tool steel. These are made in different grades according to the work to be done. The Carpenter Steel Company divides them into three classes for the following uses.

1. **Average carbon tools:** Drills, reamers, taps and dies, blanking dies, striking dies, coining dies, forming dies, bending dies, button dies, punches, mandrels, arbors, jig bushings, cutters and hobs, dowel pins, stamps, lathe centers, knurls, studs, adapters, jig feet, plugs, ring and snap gages.
2. **Tools requiring maximum wear resistance and fair toughness are:** Drawing dies, cold extrusion dies and punches, shaving dies, sectional blanking dies, forming tools and rolls, burnishing tools, cutting tools for brass and non-ferrous metals, finishing reamers, spinning tools.

3. Tools requiring maximum toughness with only fair wear resistance are: Heavy-duty perforating punches, knockout pins, fingers, clutch pins, stops, indexing pins, screw extractors, coining dies, shear blades, spring collets, feed fingers, pneumatic chisels, rivet busters, nail sets, flaring tools, sledges, pipe cutters, screw drivers, drift pins, rivet sets.

Similar gradings are made for oil hardening and high-speed steels.

ALLOY STEELS

Alloy steels are used because of greater hardness, strength, toughness, wear resistance, and uniformity, as well as less distortion or liability to crack in hardening. Selection of steels for special uses is important. The Carpenter Steel Company divides them into three groups: low carbon, *case hardening;* medium carbon, *tough tempering,* for axles, shafts, bolts, etc.; high carbon, *hard tempering,* for gears, clutch parts, etc. In some cases the same steel can be used for both the second and third groups. Choice of the best steel for different work will be easier after studying the table on comparative properties of the two types of steel.

TABLE 1.—COMPARATIVE PROPERTIES OF CASE-HARDENING AND HARD-TEMPERING STEELS

	Case-Hardening Steel	Hard-Tempering Steel
Initial cost of steel	Same	Same
Cost of forging	Less	Greater
Cost of annealing forgings	Less	Greater
Cost of machining	Less	Greater
Cost of finish heat-treatment	Greater	Less
Distortion in heat-treating	Greater	Less
Ease of straightening	Easier	More difficult
Hardness of surface	Greater	Less
Wear resistance	Greater	Less
Toughness of surface	Less	Greater
Tendency to pit under high unit pressures	Less	Greater
Tendency to upset under heavy loads	Greater	Less
Over-all strength of part	**Less**	**Greater**

Choosing between a Case-Hardening Steel and a Tempering Steel

In making a gear, for example, the question frequently comes up —should it be made from a *case-hardening* steel or a *tempering* steel? Table 1 of comparison will be helpful. The comparison is made between steels of the *same alloy content*—one of them having low carbon for case-hardening and the other having about 0.50% carbon for tempering.

TABLE 2.—CHEMICAL COMPOSITIONS OF S.A.E. ALLOY STEELS[1]

Nickel Steels

S.A.E. No.	Carbon Range	Manganese Range	Phosphorus Maximum	Sulphur Maximum	Nickel Range
2015	0.10–0.20	0.30–0.60	0.040	0.050	0.40–0.60
2115	0.10–0.20	0.30–0.60	0.040	0.050	1.25–1.75
2315	0.10–0.20	0.30–0.60	0.040	0.050	3.25–3.75
2320	0.15–0.25	0.30–0.60	0.040	0.050	3.25–3.75
2330	0.25–0.35	0.50–0.80	0.040	0.050	3.25–3.75
2335	0.30–0.40	0.50–0.80	0.040	0.050	3.25–3.75
2340	0.35–0.45	0.60–0.90	0.040	0.050	3.25–3.75
2345	0.40–0.50	0.60–0.90	0.040	0.050	3.25–3.75
2350	0.45–0.55	0.60–0.90	0.040	0.050	3.25–3.75
2515	0.10–0.20	0.30–0.60	0.040	0.050	4.75–5.25

Nickel-Chromium Steels

S.A.E. No.	Carbon Range	Manganese Range	Phosphorus Max.	Sulphur Max.	Nickel Range	Chromium Range
3115	0.10–0.20	0.30–0.60	0.040	0.050	1.00–1.50	0.45–0.75
3120	0.15–0.25	0.30–0.60	0.040	0.050	1.00–1.50	0.45–0.75
3125	0.20–0.30	0.50–0.80	0.040	0.050	1.00–1.50	0.45–0.75
3130	0.25–0.35	0.50–0.80	0.040	0.050	1.00–1.50	0.45–0.75
3135	0.30–0.40	0.50–0.80	0.040	0.050	1.00–1.50	0.45–0.75
3140	0.35–0.45	0.60–0.90	0.040	0.050	1.00–1.50	0.45–0.75
X3140	0.35–0.45	0.60–0.90	0.040	0.050	1.00–1.50	0.60–0.90
3145	0.40–0.50	0.60–0.90	0.040	0.050	1.00–1.50	0.45–0.75
3150	0.45–0.55	0.60–0.90	0.040	0.050	1.00–1.50	0.45–0.75
3215	0.10–0.20	0.30–0.60	0.040	0.050	1.50–2.00	0.90–1.25
3220	0.15–0.25	0.30–0.60	0.040	0.050	1.50–2.00	0.90–1.25
3230	0.25–0.35	0.30–0.60	0.040	0.050	1.50–2.00	0.90–1.25
3240	0.35–0.45	0.30–0.60	0.040	0.050	1.50–2.00	0.90–1.25
3245	0.40–0.50	0.30–0.60	0.040	0.050	1.50–2.00	0.90–1.25
3250	0.45–0.55	0.30–0.60	0.040	0.050	1.50–2.00	0.90–1.25
3312	max. 0.17	0.30–0.60	0.040	0.050	3.25–3.75	1.25–1.75
3325	0.20–0.30	0.30–0.60	0.040	0.050	3.25–3.75	1.25–1.75
3335	0.30–0.40	0.30–0.60	0.040	0.050	3.25–3.75	1.25–1.75
3340	0.35–0.45	0.30–0.60	0.040	0.050	3.25–3.75	1.25–1.75
3415	0.10–0.20	0.30–0.60	0.040	0.050	2.75–3.25	0.60–0.95
3435	0.30–0.40	0.30–0.60	0.040	0.050	2.75–3.25	0.60–0.95
3450	0.45–0.55	0.30–0.60	0.040	0.050	2.75–3.25	0.60–0.95

Table 2.—Chemical Compositions of S.A.E. Alloy Steels [1]—*Continued*

Molybdenum Steels

S.A.E. No.	Carbon Range	Manganese Range	Phos. Maximum	Sulphur Maximum	Chromium Range	Nickel Range	Molybdenum Range
4130	0.25–0.35	0.50–0.80	0.040	0.050	0.50–0.80	....	0.15–0.25
X4130	0.25–0.35	0.40–0.60	0.040	0.050	0.80–1.10	....	0.15–0.25
4135	0.30–0.40	0.60–0.90	0.040	0.050	0.80–1.10	....	0.15–0.25
4140	0.35–0.45	0.60–0.90	0.040	0.050	0.80–1.10	....	0.15–0.25
4150	0.45–0.55	0.60–0.90	0.040	0.050	0.80–1.10	....	0.15–0.25
4340	0.35–0.45	0.50–0.80	0.040	0.050	0.50–0.80	1.50–2.00	0.30–0.40
4345	0.40–0.50	0.50–0.80	0.040	0.050	0.60–0.90	1.50–2.00	0.15–0.25
4615	0.10–0.20	0.40–0.70	0.040	0.050	....	1.65–2.00	0.20–0.30
4620	0.15–0.25	0.40–0.70	0.040	0.050	....	1.65–2.00	0.20–0.30
4640	0.35–0.45	0.50–0.80	0.040	0.050	....	1.65–2.00	0.20–0.30
4815	0.10–0.20	0.40–0.60	0.040	0.050	....	3.25–3.75	0.20–0.30
4820	0.15–0.25	0.40–0.60	0.040	0.050	....	3.25–3.75	0.20–0.30

Chromium Steels

S.A.E. No.	Carbon Range	Manganese Range	Phosphorus maximum	Sulphur Maximum	Chromium Range
5120	0.15–0.25	0.30–0.60	0.040	0.050	0.60–0.90
5140	0.35–0.45	0.60–0.90	0.040	0.050	0.80–1.10
5150	0.45–0.55	0.60–0.90	0.040	0.050	0.80–1.10
52100	0.95–1.10	0.20–0.50	0.030	0.035	1.20–1 50

Chromium-Vanadium Steels

S.A.E. No.	Carbon Range	Manganese Range	Phos. Maximum	Sulphur Maximum	Chromium Range	Vanadium Minimum	Vanadium Desired
6115	0.10–0.20	0.30–0.60	0.040	0.050	0.80–1.10	0.15	0.18
6120	0.15–0.25	0.30–0.60	0.040	0.050	0.80–1.10	0.15	0.18
6125	0.20–0.30	0.60–0.90	0.040	0.050	0.80–1.10	0.15	0.18
6130	0.25–0.35	0.60–0.90	0.040	0.050	0.80–1.10	0.15	0.18
6135	0.30–0.40	0.60–0.90	0.040	0.050	0.80–1.10	0.15	0.18
6140	0.35–0.45	0.60–0.90	0.040	0.050	0.80–1.10	0.15	0.18
6145	0.40–0.50	0.60–0.90	0.040	0.050	0.80–1.10	0.15	0.18
6150	0.45–0.55	0.60–0.90	0.040	0.050	0.80–1.10	0.15	0.18
6195	0.90–1.05	0.20–0.45	0.030	0.035	0.80–1.10	0.15	0.18

TABLE 2.—CHEMICAL COMPOSITIONS OF S.A.E. ALLOY STEELS [1]—*Continued*

Tungsten Steels

S.A.E. No.	Carbon Range	Manganese Range	Phos. Maximum	Sulphur Maximum	Chromium Range	Tungsten Range
71360	0.50–0.70	0.30	0.035	0.040	3.00–4.00	12.00–15.00
71660	0.50–0.70	0.30	0.035	0.040	3.00–4.00	15.00–18.00
7260	0.50–0.70	0.30	0.035	0.040	0.50–1.00	1.50– 2.00

Silicon-Manganese Steels

S.A.E. No.	Carbon Range	Manganese Range	Phosphorus Maximum	Sulphur Maximum	Silicon Range
9255	0.50–0.60	0.60–0.90	0.040	0.050	1.80–2.20
9260	0.55–0.65	0.60–0.90	0.040	0.050	1.80–2.20

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[1] *S.A.E. Handbook*, 1936. (These are as adopted by the Society of Automotive Engineers in January, 1935, and are subject to future revision.)

Characteristics of Tool Steel

The characteristics of tool steel, as shown in Fig. 1 are for general information, not for the selection of specific steels for specific uses. It will serve as a guide for making a chart to fit the particular needs of any shop. In making up such a chart for shop use, the best experience available in that shop should be included in that chart and all later experience added as it occurs. It may be well to add trade names, as well as the shop symbols used, as these make a convenient reference. An additional list of the heat-treatments of each steel will be of value.

Deep Freezing

Deep freezing is another application of artificial cold to machine work. It has been found that cutters of various kinds have a greatly increased life if they are frozen for several hours at 120 degrees below zero and then permitted to return to room temperature. It is claimed that broken milling cutters can be brazed, and will become hardened if deep frozen.

Deep freezing is also said to improve the machining quality of S.A.E. 4340. Some other steels, such as S.A.E. 2512, can be made somewhat harder by deep freezing after heat treatment. The effect of the treatment depends on the content of the steel, those high in nickel being most affected.

CLASS OF STEEL	CHIEF CHARACTERISTIC-FORMING ELEMENTS																																TYPICAL TOOL USES
	Carbon					Mn			Chromium						Va			Mo			Tungsten					Cobalt				Ni		Si	
	ADDS HARDENING PROPERTY, INCREASES TENSILE STRENGTH TOUGHNESS AND WEAR RESISTANCE					INCREASES HARDNESS, WEAR RESISTANCE AND STRENGTH, DECREASES TOUGHNESS			FORMS CARBIDES AND INCREASES HARDENING POWER. DEEP HARDENS AND DECREASES WARPAGE, INCREASES SHOCK RESISTANCE						REFINES GRAIN INCREASES FATIGUE RESISTANCE. ADDS STRENGTH, DEC. DISTORTION			HARDENS AND ADDS RED HARDNESS, INCREASES WEAR RESISTANCE AND STRENGTH			REFINES GRAIN ADDS RED HARDNESS INCREASES WEAR RESISTANCE INCREASES STRENGTH AND SHOCK RESISTANCE					REFINES GRAIN INCREASES RED HARDNESS INCREASES STRENGTH				INCREASES STRENGTH, TOUGHNESS, HARDNESS		INCR. HARDNESS & ELASTIC LIMITS	
	0.25-0.54	0.55-0.74	0.75-1.2	1.25-1.6	2.0-2.5	0.40-0.90	1.0-1.5	1.55-2.0	0-0.45	0.45-0.74	0.75-1.0	1.4-2.0	3.2-4.75	10.0-14.0	0.15-0.50	0.75-1.25	1.5-2.0	0-0.60	0.61-1.0	8.0-9.0	0.4-2.5	3.5-5.0	5.0-10.0	13.0-16.0	17.0-20.0	0.5-0.80	2.0-3.5	3.0-9.0	10.0-14.0	0-0.50	1.5-5.0	1.0-2.0	
MEDIUM CARBON		●																															CHISELS, HAMMERS, HAMMER DIES
HIGH CARBON			●																														LATHE TOOLS DIES FILES, CUTTERS
VERY-HIGH CARBON				●																													TAPS, DIES SHEARS, ENGRAVING TOOLS
NON DEFORMING			●					●																									DIES, BROACHES
			●				●	●		●																							DIES, BROACHES, PLUG AND THREAD GAGES
			●			●				●	●																						HOT DIES, CAMS WEARING PARTS
			●										●																				HEADER DIES FORGING DIES
VANADIUM	●	●	●	●		●					●				●																		SUPER TOOL STEELS TO REPLACE CARBON STEELS IN ALL CARBONS THEY ARE STRONGER AND TOUGHER
		●	●	●											●																		
WEAR RESISTANT					●									●		●																	PRODUCTION TOOLS, DIES
			●					●	●									●															
			●			●				●								●															TAPS
WEAR AND SHOCK RESISTANT				●										●		●			●														SUB-PRESS DIES FORGING DIES
				●										●	●				●														STAMPING AND COLD FORGING DIES
			●	●			●			●											●												WIRE-DRAWING DIES, REAMERS
KEEN EDGE			●	●		●			●						●						●												TAPS DRILLS BLANKING DIES
SHOCK RESISTANT	●											●			●						●												HIGH-PRODUCTION TOOLS
			●				●			●					●					●	●												
HIGH SPEED		●											●			●					●												CUTTING TOOLS TO REPLACE HIGH TUNGSTEN STEELS
WEAR RESISTANT				●																		●											PLUG GAGES, CAM ROLLS, FORGING DIES
HOT WORK	●												●		●								●										HOT FORMING DIES
	●												●			●								●									
	●					●							●		●									●									
HIGH SPEED		●											●			●									●								CUTTING TOOLS
			●										●				●	●							●								
			●										●				●		●						●								
WEAR RESISTANT				●										●	●				●							●							HEAVY FORMING DIES (CAST)
				●										●						●							●						
SUPER HIGH SPEED		●											●			●		●							●			●					CUTTING TOOLS
			●										●				●		●						●			●					
		●											●			●		●							●				●				
NON-DEFORMING					●									●																●			THREAD ROLLING DIES BROACHES, GAGES
WEAR AND SHOCK RESISTANT			●			●					●																				●		HEAVY-DUTY SHEARS PAWLS, INDEXING PINS
	●					●									●			●														●	PNEUMATIC TOOLS
					●									●							●											●	COINING AND DRAWING DIES
FATIGUE RESISTANT		●				●			●						●																	●	IMPACT TOOLS

FIG. 1.—Characteristics of Tool Steel

TABLE 3.—RECOMMENDED HEAT-TREATMENT OF S.A.E. STEELS[1]

Case-Hardening Alloy Steels

S.A.E. No.	Treat. No.	Normalize	Carburize °F.	Cooling Method	Reheat °F.	Cooling Method	Reheat °F.	Cooling Method	Draw °F.
2015	I	......	1650/1700	Quench	......	......	......	......	250/300
	II	......	1650/1700	Quench	1400/1450	Quench	......	......	250/300
	III	......	1650/1700	In box	1400/1450	Quench	......	......	250/300
	IV	......	1650/1700	In box	1650/1700	Quench	1400/1450	Quench	250/300
	V	......	1500/1650*	Quench	......	......	......	......	If desired
2115	I	......	1650/1700	Quench	......	......	......	......	250/300
	II	......	1650/1700	Quench	1375/1425	Oil	......	......	250/300
	III	......	1650/1700	In box	1375/1425	Oil	......	......	250/300
	IV	......	1650/1700	In box	1650/1700	Oil	1375/1425	Oil	250/300
	V	......	1650/1700*	Oil	......	......	......	......	If desired
2315 and 2320	I	Yes† to obtain greatest accuracy and highest strength	1650/1700	Quench	1350/1400‡	Oil	......	......	250/300
			1650/1700	Quench	1450/1500§	Oil	......	......	250/300
	II		1650/1700	In box	1350/1400‡	Oil	......	......	250/300
			1650/1700	In box	1450/1500§	Oil	......	......	250/300
	III		1650/1700	In box	1500/1550	Oil	1350/1400	Oil	250/300
	IV		1650/1700	Quench	......	......	......	......	250/500
	V		1450/1650*	Oil	......	......	......	......	If desired
2515	I	Yes† and anneal for structure or machinability	1650/1700	In box	1325/1375‡	Oil	......	......	250/400
			1650/1700	In box	1400/1475§	Oil	......	......	250/400
	II		1650/1700	In box	1500/1550	Oil	1325/1375	Oil	250/400
3115 and 3120	I	Yes† to reduce distortion and improve machining	1650/1700	Quench	1400/1450‡	Quench	......	......	250/300
			1650/1700	Quench	1450/1500§	Quench	......	......	250/300
	II		1650/1700	In box	1400/1450‡	Quench	......	......	250/300
			1650/1700	In box	1450/1500§	Quench	......	......	250/300
	III		1650/1700	In box	1525/1575	Oil	1375/1425	Quench	250/300
	IV		1650/1700	Quench	......	......	......	......	250/500
	V		1500/1650*	Oil	......	......	......	......	If desired

3215 and 3220	I	Yes† and anneal for structure or machinability	1650/1700	Quench	1375/1425‡	Oil	....	......	250/500
			1650/1700	Quench	1425/1475§	Oil	....	......	250/500
	II		1650/1700	In box	1375/1425‡	Oil	....	......	250/500
			1650/1700	In box	1425/1475§	Oil	....	......	250/500
	III		1650/1700	In box	1525/1575	Oil	1375/1425	Oil	250/500
3312	I	Yes† and anneal for machinability	1650/1700	Quench	1375/1425	Oil	....	......	250/300
	II		1650/1700	In box	1375/1425‡	Oil	....	......	250/300
			1650/1700	In box	1450/1500§	Oil	....	......	250/300
	III		1650/1700	In box	1525/1575	Oil	1375/1425	Oil	250/300
	IV		1650/1700	Quench	....	......	....	......	250/400
3415	I	Yes† and anneal for machinability	1650/1700	Quench	1375/1425‡	Oil	....	......	250/300
			1650/1700	Quench	1450/1500§	Oil	....	......	250/300
	II		1650/1700	In box	1375/1425‡	Oil	....	......	250/300
			1650/1700	In box	1450/1500§	Oil	....	......	250/300
	III		1650/1700	In box	1500/1550	Oil	1375/1425	Oil	250/300
	IV		1650/1700	Quench	....	......	....	......	250/400
4615 and 4620	I	Yes†	1650/1700	Quench	1425/1475‡	Oil	....	......	250/300
		Yes†	1650/1700	Quench	1475/1525§	Oil	....	......	250/300
	II	Yes†	1650/1700	In box	1425/1475‡	Oil	....	......	250/300
		Yes†	1650/1700	In box	1475/1525§	Oil	....	......	250/300
	III	Yes†	1650/1700	In box	1525/1575	Oil	1375/1425	Oil	250/300
	IV	Yes†	1650/1700	Quench	....	......	....	......	250/400
4815 and 4820	I	Yes† and anneal for structure and machinability	1650/1700	Quench	1350/1400‡	Oil	....	......	250/300
			1650/1700	Quench	1450/1500§	Oil	....	......	250/300
	II		1650/1700	In box	1350/1400‡	Oil	....	......	250/300
			1650/1700	In box	1450/1500§	Oil	....	......	250/300
	III		1650/1700	In box	1550/1650	Oil	1350/1400	Oil	250/300
	IV		1650/1700	Quench	....	......	....	......	250/500
5120	I	Yes†	1650/1700	Quench	1425/1475‡	Oil	....	......	250/300
		Yes†	1650/1700	Quench	1475/1525§	Oil	....	......	250/300
	II	Yes†	1650/1700	In box	1425/1475‡	Oil	....	......	250/300
		Yes†	1650/1700	In box	1475/1525§	Oil	....	......	250/300
	III	Yes†	1650/1700	In box	1600/1650	Oil	1425/1475	Oil	250/300
	IV	....	1500/1650*	Quench	....	......	....	......	If desired

TABLE 3.—RECOMMENDED HEAT-TREATMENT OF S.A.E. STEELS—*Continued*

S.A.E. No.	Treat. No.	Normalize	Carburize °F.	Cooling Method	Reheat °F.	Cooling Method	Reheat °F.	Cooling Method	Draw °F.
6115 and 6120	I	Yes†	1650/1700	Quench	1425/1475‡	Oil	....	......	250/350
		Yes†	1650/1700	Quench	1475/1525§	Oil	....	......	250/350
	II	Yes†	1650/1700	In box	1425/1475‡	Oil	....	......	250/350
		Yes†	1650/1700	In box	1475/1525§	Oil	....	......	250/350
	III	Yes†	1650/1700	In box	1600/1650	Oil	1425/1475	Oil	250/350
	IV	....	1500/1650*	Oil	....	......	....	......	If desired

[1] Tabulated from S.A.E. Handbook 1936. These heat-treating instructions are not a part of the S.A.E. standard specifications, and the society recommends that they should not be used in conjunction with the chemical compositions in purchasing steels. They are given only as helpful information.

* In cyanide or activated baths.

† Normalize at least 50°F. above carburizing temperature.

‡ For case hardness only.

§ For core hardness.

TABLE 3.—RECOMMENDED HEAT-TREATMENT OF S.A.E. STEELS [1]—*Continued*
Tempering Alloy Steels

S.A.E. No.	Treat. No.	Normalize	Anneal	Hardening Temperature	Cooling Method	Draw
2330	I	....	....	1450/1500	Quench	To required hardness
2335	II	Yes	Yes—(to machine)	1450/1500	Quench	To required hardness
2340	I	....	....	1425/1475	Oil	To required hardness
2345	II	Yes	Yes—(to machine)	1425/1475	Oil	To required hardness
2350	I	Yes	Yes—(to machine)	1425/1475	Oil	To required hardness
3125	I	....	....	1500/1550	Quench	To required hardness
3130	II	1650/1750	....	1500/1550	Quench	To required hardness
3135	I	....	....	1500/1550	Oil	To required hardness
3140	II	1650/1750	Yes—(to machine)	1500/1550	Oil	To required hardness
X3140	I	....	....	1500/1550	Oil	To required hardness
	II	Yes	Yes—(to machine)	1500/1550	Oil	To required hardness
3145 3150	I	Yes	Yes—(to machine)	1500/1550	Oil	To required hardness
3230	I	Yes	Yes—(to machine)	1500/1550	Oil	To required hardness
3240	I	Yes	Yes—(to machine)	1475/1525	Oil	To required hardness
3245 3250	I	Yes	Yes—(to machine)	1425/1475	Oil	To required hardness
3325	I	Yes	Yes—(to machine)	1475/1525	Oil	To required hardness
3335 3340	I	Yes	Yes—(to machine)	1425/1475	Oil	To required hardness
3435	I	Yes	Yes—(to machine)	1425/1475	Oil	To required hardness
3450	I	Yes	Yes—(to machine)	1400/1450	Oil	To required hardness
4130 X4130	I	Yes	Yes—(to machine)	1550/1650	Quench	To required hardness
4140	I	Yes	Yes—(to machine)	1525/1625	Oil	To required hardness
4150	I	Yes	Yes—(to machine)	1500/1600	Oil	To required hardness

TABLE 3.—RECOMMENDED HEAT-TREATMENT OF S.A.E. STEELS [1]—*Continued*

S.A.E. No.	Treat. No.	Normalize	Anneal	Hardening Temperature	Cooling Method	Draw
4340 4345	I	Yes	Yes—(to machine)	1475/1525	Oil	To required hardness
4640	I**	Yes	Yes—(to machine)	1450/1500*	Oil	350/450
	II	Yes	Yes—(to machine)	1450/1550	Oil	To required hardness
5140	I	Yes	Yes—(to machine)	1500/1600	Oil	To required hardness
	II**	Yes	Yes—(to machine)	1475/1525*	Oil	375/450
5150	I	Yes	Yes—(to machine)	1450/1550	Oil	To required hardness
	II**	Yes	Yes—(to machine)	1475/1525	Oil	375/425
52100	I	....	1350/1450 and cool slowly	1425/1475 1500/1600	Water Oil	To required hardness To required hardness
6125 6130	I	....	....	1575/1625	Quench	To required hardness
	II	1650/1750	....	1575/1625	Quench	To required hardness
6135 6140	I	Yes	Yes—(to machine)	1550/1650	Oil	To required hardness
6145 6150	I	Yes	Yes—(to machine)	1525/1625	Oil	To required hardness
6195	I	....	1330/1380 and cool slowly	1425/1475 1500/1600	Water Oil	To required hardness To required hardness
9255 9260	I	....	....	1500/1650	Oil	To required hardness

* In cyanide or actuated baths. ** For gear.

The Rockwell Test

The Rockwell test, like the Brinell test, measures indentation hardness (resistance to penetration) but differs in that the Rockwell Tester is a direct-reading instrument. Two loads are applied: one, resulting from bringing the specimen into spring-loaded contact with the indenter, which breaks through dirt and irregularities of finish on surface of specimen; and the other, which is the major or testing load, causing an increase in penetration due to increment of load. The dial readings are actually readings of penetrator motion with respect to the head of the machine, and, as the operator sets the dial to zero after the minor load is applied, the readings indicate the increment of indentation due to the increment of load. To meet the general concept high numbers for hard materials, the pointer is made to move to lesser and lesser numerical values as the indentation increases.

The Rockwell Tester is made in two general types. The Normal type applies a minor load of 10 kilograms (about 22 pounds) and selective major loads of 60 kilograms, 100 kilograms, and 150 kilograms. The Superficial type applies a minor load of 3 kilograms and selective major loads of 15 kilograms, 30 kilograms, and 45 kilograms. The purpose of the Superficial type is to test to only a very shallow extent, as required on lightly carburized or nitrided steel and any metal in sheet or strip form that is too thin for indentation with the Normal type.

One point of hardness on the dial of the Normal type corresponds to 0.00008 inch in depth of impression. The Superficial type has a depth-measuring system of twice that sensitivity.

With both the Normal and Superficial type of the Rockwell Tester, hardened steel is tested with a diamond penetrator ground to a cone of 120 degrees and a tangentially spherical point of 0.2 millimeter radius. Unhardened steel and brass are tested with a $\frac{1}{16}$ inch diameter steel ball penetrator.

Principally Used Scales.—The most extensively used scales (combinations) are as follows:

1. With a spheroconical diamond penetrator different loads give scale A for 60 kilograms; scale C for 150 kilograms; scale 15-N for 15 kilograms; scale 30-N for 30 kilograms.
2. With $\frac{1}{16}$-inch ball penetrator, the loads give scale B for 100 kilograms; scale F for 60 kilograms; scale 15-T for 15 kilograms; scale 30-T for 30 kilograms.

Scleroscope Reading

In the Shore Scleroscope, a miniature drop hammer tup falls from a fixed height to the surface of the metal being tested. The height of the rebound indicates the hardness on an arbitrary scale which has 115 divisions, these meeting all usual requirements. This method can be applied to any material which will take a permanent set under impact. For, no matter how hard the material, the falling weight, weighing about 40 grains, makes a dent which can be seen with a glass.

The following table shows the readings which will be obtained on the Scleroscope for the materials indicated, thus giving the comparative hardness of the materials.

Scleroscope Hardness Scale

Metal	Annealed	Hammered
Lead — cast	2– 5	3– 7
Babbitt	4– 9	
Gold	5	8½
Silver	6½	20– 30
Brass — cast	7–35	
Pure Tin — cast	8	12
Brass — drawn	10–15	20– 45
Bismuth — cast	9	
Platinum	10	17
Copper — cast	6	14– 20
Zinc — cast	8	20
Iron — pure	18	25– 30
Mild steel, 0.15 carbon	22	30– 45
Nickel Anode — cast	31	55
Iron, gray — cast	30–45	
Iron, gray — chilled		50– 90
Steel, tool, 1% carbon	30–35	40– 50
Steel, tool, 1.65% carbon	35–40	
Vanadium steel	35–45	
Chrome — Nickel	47	
Chrome — Nickel, hardened		60– 95
Steel, high speed, hardened		70–105
Steel, carbon, tool, hardened		90–110

Note.—These figures vary with the composition and density of the metals. They are about $\frac{1}{6}$ those of the Brinell test for equal hardness, varying somewhat with the kind of metal.

HARDENING STEEL BY SHOT-BLASTING AND MAGNETISM

It is well known that some steel "work hardens" from contact with the cutting tools, especially after they become dull. Shot-blasting with steel balls also hardens the surface by a peening action. In Britain this is called "cloudburst." Edward G. Herbert has found that work hardened steel becomes harder still when placed across the poles of an electro-magnet and rotated first in one direction and then in the other. We know of no practical application of this method as yet.

FUNDAMENTAL HARDENING RULES[1]

Heating is to be done gradually and penetratingly, until the whole section of the part of the tool to be hardened has reached the right hardening temperature of the particular steel used. The tool should be kept at the hardening temperature only long enough to permit thorough heating.

[1] Weston Electrical Instrument Corporation.

The tool should then be hardened in accordance with its requirements more or less vigorously by quenching in a suitable hardening medium. Temper can be drawn if required.

FREQUENT FAULTS IN HARDENING

Fault in Hardening	Appearance of the Tool Resulting from the Fault	Appearance of Fracture	Possible Means of Correcting the Faults of Hardening
The tool has been heated insufficiently, that is, has not been heated at the correct hardening temperature	Has not been hardened or is insufficiently hard. Has retained its scale wholly or in part. Can be filed	Has more or less the appearance of unhardened steel	Hardening is to be repeated at a higher temperature
The tool has been heated to above the correct hardening temperature, that is, overheated	Sufficient hardness; normal amount of scale; cannot be filed. The tool may crack easily during hardening owing to insufficient toughness. Breaks away during use	Varying from fine to coarse grain, in some cases, glittering; occasionally stony appearance	Should the overheating be only slight, hardening can be repeated at a lower, that is, the right, temperature. Should the heating, however, be greater, the steel should be annealed beforehand and then rehardened. If, as with chisels, the form of the tool will permit it, the steel should be reforged
The tool has been very severely overheated, that is, burned	Sufficient hardness; normal amount of scale; cannot be filed. Owing to lack of toughness, the tool cracks and breaks out easily during use	Coarse grain to coarse crystalline, strong white sparkle	A burned tool cannot be rendered serviceable
The tool has not been sufficiently protected against decarburization of the surface during heating	Has apparently not taken sufficient hardness; imperfect scaling; surface can be filed; beneath soft decarbonized surface proper hardness is often found	A wider or narrower edging, depending on the intensity of the decarbonization, will show on the outside. This edging will be very sparkling and resemble cast iron. Below it the grain will be in ac-	Grind away the decarbonized surface. If this is not possible and the decarbonization is not deep, the tool may be annealed in a case-hardening material (that is, carbonized leather) and then rehardened.

FREQUENT FAULTS IN HARDENING—*Continued*

Fault in Hardening	Appearance of the Tool Resulting from the Fault	Appearance of Fracture	Possible Means of Correcting the Faults of Hardening
		cordance with hardening	Should the decarburization be deep, anneal and reforge the piece and then harden afresh
The tool has been heated too quickly and irregularly	Unequal hardness (the edges are generally sufficiently hard); imperfect scaling. Can be filed in places. The tool cracks easily, corners or teeth break out with shell fractures, large pieces burst	Unequal appearance. Partly unhardened, partly properly hardened. Often overheated grain on edges and thin portions	Anneal and reharden correctly
The part of the tool to be hardened has not been cooled suddenly enough, either because the hardening medium has become too warm or because a wall of steam has been allowed to form between the tool and the hardening medium	Insufficient hardness, especially with large pieces. Edges are generally hard. Surfaces, particularly large ones, can be filed, however, even though they scale properly	Only edges and thin portion properly hardened, otherwise—particularly on the surface—unhardened or not quite enough grain	The hardening is to be repeated, care being used that the cooling takes place rapidly enough, either by the use of a spray or blast pipe or by moving the piece about in the hardening medium. Complicated pieces should be annealed beforehand
The tool has been hardened in a hardening medium (for example; oil, air, etc.) which was too mild for the quality of the steel, or for the particular purpose for which the tool is required	Insufficient hardness; edges and thin sections sometimes hard; larger sections and surfaces soft; generally insufficient scaling; can be filed in parts	Resembles at the soft parts more or less the fracture of the unhardened steel	Hardening is to be repeated in a stronger hardening medium
The tool has been hardened in a hardening medium (for example, brine) which was too strong for the quality of the steel or for the particular purpose for which the tool is required	Proper hardness, normal scaling, cannot be filed; hardening cracks appear; great distortion; tool is brittle	Hardening grain is good; very deep; sometimes shows complete hardening	Relieve the brittleness by drawing the temper

The Natural Fracture of the Tool Steel (Unannealed, Unhardened).—This should show an even gray, dull grain, which is coarse with soft steels and finer with hard steels. Alloy steels show a fracture in accordance with the alloy used and have a more or less velvety appearance and a coloring of their own.

The Fracture of Annealed Tool Steel.—Through proper annealing the texture of the steel becomes brighter, the fracture is more regular, the grain rather fine. The brightness, however, is easily distinguishable from the sparkling brightness of overheated steel.

The Fracture of Badly Annealed Tool Steel.—Insufficiently annealed steel has a fracture more or less like the natural fracture. Overannealed steel has a coarser crystalline and very brilliant fracture. Should air have penetrated to the steel during the process of annealing, the fracture will show, on the surface, a decarburized edging resembling cast iron.

The Fracture of Hardened Tool Steel.—The fracture of the hardened layer of a properly treated steel will have the finest grain that it is possible to attain with the particular quality of steel used. This grain will be very fine, velvety, and dull. The differences of grain between a soft and hard steel will almost entirely disappear at the hardened layer. The fracture of alloyed steels will have a particularly fine dull texture. Depth of the hardened layer depends on the chemical composition of the steel and, in some qualities, also on the manner of annealing.

The Right Hardening Temperature of a Steel.—This is the lowest temperature at which the steel will take a good hardness. At this temperature the steel will have the best combination of hardness and toughness. If treated at a higher temperature, it will simply lose in toughness without gaining in hardness. This correct hardening temperature is not the same in all qualities of steel.

The Right Tempering Color.—This is the color by which the tool obtains sufficient toughness for the purpose for which it is intended while retaining the greatest possible hardness.

HEATING RATE OF VARIOUS SHAPES

The relative time needed to heat pieces of different shapes is shown in Table 3.

Work with black surface heats faster than that with bright surfaces. The table, from the Carpenter Steel Company, shows the comparative rates.

In drawing the temper of carbon tools remember that both time and temperature affect the results. The lower the drawing heat, the more time must be given to relieve strains. A general rule is to draw at least 1 hour for every inch in thickness. This should be doubled where there are sharp corners or unequal sections.

TIME REQUIRED TO HEAT MONEL, NICKEL, AND INCONEL TO FORGING TEMPERATURE

Size of Round or Square, in Inches	Total Time in Furnace, in Minutes		
	Monel	Nickel	Inconel
½	2-5	3-7	4-10
1	6-10	9-16	12-20
2	16-23	23-35	34-45
3	30-40	45-60	60-80
4	45-60	70-90	90-120
6	75-100	110-140	150-200

Furnace Atmosphere

Three types of furnace atmosphere are now recognized: *oxidizing*, *neutral*, and *reducing*. An *oxidizing* atmosphere has more air than is necessary for combustion. A *reducing* atmosphere has too little air for combustion leaving an excess of gas. Complete combustion produces a *neutral* atmosphere, which it is almost impossible to maintain.

An oxidizing atmosphere produces scale and tends to melt this scale on the surface of the work which some call "sweating." A reducing atmosphere prevents scale at the high temperatures used in hardening high-speed steel and is not active in decarburizing the surface. In a reducing atmosphere the excess fuel will burn at the ports in contact with the outside air. A wood block will char but not flame in a reducing atmosphere.

QUENCHING BATHS

Still, fresh water is not a good cooling bath. Fresh water dissolves gas from the air. This gas settles on the tool, forming bubbles that retard cooling at these points, leaving soft spots on the work. Salt in the water prevents the formation of the gas and throws the scale better than fresh water, this being its only advantage. From 5 to 10 per cent of salt in a still tank is good for quenching tool steel. Temperature should be from 70 to 100°F. the year round. A 5 per cent caustic soda bath is fast and efficient but is corrosive to hands and clothes. It is seldom necessary.

Oil Baths

Oil baths of many kinds are used for high-speed and other oil-hardening steels. It should have a flash point of 350°F., or higher, and low viscosity. It should not have a bad odor. Oil flows freely at 140°F. and quenches well at that point. It is circulated through cooling coils where large quantities of work are handled. On cold mornings it should be heated to 90 or 100°F. before using.

Temperature Conversion Tables

−459.4–0						1–50						51–100						101–750								
C.		F.	C.		F.	C.		F.	C.		F.	C.		F.	C.		F.	C.		F.	C.		F.	C.		F.
−273	**−459.4**		−134	**−210**	−346	−17.2	**1**	33.8	−3.33	**26**	78.8	10.6	**51**	123.8	24.4	**76**	168.8	43	**110**	230	177	**350**	662	260	**500**	932
−268	**−450**		−129	**−200**	−328	−16.7	**2**	35.6	−2.78	**27**	80.6	11.1	**52**	125.6	25.0	**77**	170.6	49	**120**	248	182	**360**	680	266	**510**	950
−262	**−440**		−123	**−190**	−310	−16.1	**3**	37.4	−2.22	**28**	82.4	11.7	**53**	127.4	25.6	**78**	172.4	54	**130**	266	188	**370**	698	271	**520**	968
−257	**−430**		−118	**−180**	−292	−15.6	**4**	39.2	−1.67	**29**	84.2	12.2	**54**	129.2	26.1	**79**	174.2	60	**140**	284	193	**380**	716	277	**530**	986
−251	**−420**		−112	**−170**	−274	−15.0	**5**	41.0	−1.11	**30**	86.0	12.8	**55**	131.0	26.7	**80**	176.0	66	**150**	302	199	**390**	734	282	**540**	1004
−246	**−410**		−107	**−160**	−256	−14.4	**6**	42.8	−0.56	**31**	87.8	13.3	**56**	132.8	27.2	**81**	177.8	71	**160**	320	204	**400**	752	288	**550**	1022
−240	**−400**		−101	**−150**	−238	−13.9	**7**	44.6	0	**32**	89.6	13.9	**57**	134.6	27.8	**82**	179.6	77	**170**	338	210	**410**	770	293	**560**	1040
−234	**−390**		− 95.6	**−140**	−220	−13.3	**8**	46.4	0.56	**33**	91.4	14.4	**58**	136.4	28.3	**83**	181.4	82	**180**	356	216	**420**	788	299	**570**	1058
−229	**−380**		− 90.0	**−130**	−202	−12.8	**9**	48.2	1.11	**34**	93.2	15.0	**59**	138.2	28.9	**84**	183.2	88	**190**	374	221	**430**	806	304	**580**	1076
−223	**−370**		− 84.4	**−120**	−184	−12.2	**10**	50.0	1.67	**35**	95.0	15.6	**60**	140.0	29.4	**85**	185.0	93	**200**	392	227	**440**	824	310	**590**	1094
−218	**−360**		− 78.9	**−110**	−166	−11.7	**11**	51.8	2.22	**36**	96.8	16.1	**61**	141.8	30.0	**86**	186.8	99	**210**	410	232	**450**	842	316	**600**	1112
−212	**−350**		− 73.3	**−100**	−148	−11.1	**12**	53.6	2.78	**37**	98.6	16.7	**62**	143.6	30.6	**87**	188.6	100	**212**	413	238	**460**	860	321	**610**	1130
−207	**−340**		− 67.8	**− 90**	−130	−10.6	**13**	55.4	3.33	**38**	100.4	17.2	**63**	145.4	31.1	**88**	190.4	104	**220**	428	243	**470**	878	327	**620**	1148
−201	**−330**		− 62.2	**− 80**	−112	−10.0	**14**	57.2	3.89	**39**	102.2	17.8	**64**	147.2	31.7	**89**	192.2	110	**230**	446	249	**480**	896	332	**630**	1166
−196	**−320**		− 56.7	**− 70**	− 94	− 9.44	**15**	59.0	4.44	**40**	104.0	18.3	**65**	149.0	32.2	**90**	194.0	116	**240**	464	254	**490**	914	338	**640**	1184
−190	**−310**		− 51.1	**− 60**	− 76	− 8.89	**16**	61.8	5.00	**41**	105.8	18.9	**66**	150.8	32.8	**91**	195.8	121	**250**	482				343	**650**	1202
−184	**−300**		− 45.6	**− 50**	− 58	− 8.33	**17**	63.6	5.56	**42**	107.6	19.4	**67**	152.6	33.3	**92**	197.6	127	**260**	500				349	**660**	1220
−179	**−290**		− 40.0	**− 40**	− 40	− 7.78	**18**	65.4	6.11	**43**	109.4	20.0	**68**	154.4	33.9	**93**	199.4	132	**270**	518				354	**670**	1238
−173	**−280**		− 34.4	**− 30**	− 22	− 7.22	**19**	67.2	6.67	**44**	111.2	20.6	**69**	156.2	34.4	**94**	201.2	138	**280**	536				360	**680**	1256
−169	**−273**	−459.4	− 28.9	**− 20**	− 4	− 6.67	**20**	68.0	7.22	**45**	113.0	21.1	**70**	158.0	35.0	**95**	203.0	143	**290**	554				366	**690**	1274
−168	**−270**	−454	− 23.3	**− 10**	14	− 6.11	**21**	69.8	7.78	**46**	114.8	21.7	**71**	159.8	35.6	**96**	204.8	149	**300**	572				371	**700**	1292
−162	**−260**	−436	− 17.8	**0**	32	− 5.56	**22**	71.6	8.33	**47**	116.6	22.2	**72**	161.6	36.1	**97**	206.6	154	**310**	590				377	**710**	1310
−157	**−250**	−418				− 5.00	**23**	73.4	8.89	**48**	118.4	22.8	**73**	163.4	36.7	**98**	208.4	160	**320**	608				382	**720**	1328
−151	**−240**	−400				− 4.44	**24**	75.2	9.44	**49**	120.2	23.3	**74**	165.2	37.2	**99**	210.2	166	**330**	626				388	**730**	1346
−146	**−230**	−382				− 3.89	**25**	77.0	10.0	**50**	122.0	23.9	**75**	167.0	37.8	**100**	212.0	171	**340**	644				393	**740**	1364
−140	**−220**	−364																						399	**750**	1382

Note.—The numbers in bold-face type refer to the temperature either in degrees Centigrade or Fahrenheit which it is desired to convert into the other scale. If converting from Fahrenheit degrees to Centigrade degrees the equivalent temperature will be found in the left column, while if converting from degrees Centigrade to degrees Fahrenheit, the answer will be found in the column on the right. These tables are a revision of those by Albert Sauveur, Professor of Metallurgy and Metallography, Harvard University, Cambridge, Mass. Copyright, 1920.

INTERPOLATION FACTORS

C.		F.	C.		F.
0.56	**1**	1.8	3.33	**6**	10.8
1.11	**2**	3.6	3.89	**7**	12.6
1.67	**3**	5.4	4.44	**8**	14.4
2.22	**4**	7.2	5.00	**9**	16.2
2.78	**5**	9.0	5.56	**10**	18.0

TEMPERATURE CONVERSION TABLES—*Continued*

751-1250						1251-1750						1751-2250						2251-3000								
C.		F.	C.		F.	C.		F.	C.		F.	C.		F.	C.		F.	C.		F.	C.		F.	C.		F.
404	**760**	1400	543	**1010**	1850	682	**1260**	2300	816	**1500**	2732	960	**1760**	3200	1099	**2010**	3650	1238	**2260**	4100	1371	**2500**	4532	1516	**2760**	5000
410	**770**	1418	549	**1020**	1868	688	**1270**	2318	821	**1510**	2750	966	**1770**	3218	1104	**2020**	3668	1243	**2270**	4118	1377	**2510**	4550	1521	**2770**	5018
416	**780**	1436	554	**1030**	1886	693	**1280**	2336	827	**1520**	2768	971	**1780**	3236	1110	**2030**	3686	1249	**2280**	4136	1382	**2520**	4568	1527	**2780**	5036
421	**790**	1454	560	**1040**	1904	699	**1290**	2354	832	**1530**	2786	977	**1790**	3254	1116	**2040**	3704	1254	**2290**	4154	1388	**2530**	4586	1532	**2790**	5054
427	**800**	1472	566	**1050**	1922	704	**1300**	2372	838	**1540**	2804	982	**1800**	3272	1121	**2050**	3722	1260	**2300**	4172	1393	**2540**	4604	1538	**2800**	5072
432	**810**	1490	571	**1060**	1940	710	**1310**	2390	843	**1550**	2822	988	**1810**	3290	1127	**2060**	3740	1266	**2310**	4190	1399	**2550**	4622	1543	**2810**	5090
438	**820**	1508	577	**1070**	1958	716	**1320**	2408	849	**1560**	2840	993	**1820**	3308	1132	**2070**	3758	1271	**2320**	4208	1404	**2560**	4640	1549	**2820**	5108
443	**830**	1526	582	**1080**	1976	721	**1330**	2426	854	**1570**	2858	999	**1830**	3326	1138	**2080**	3776	1277	**2330**	4226	1410	**2570**	4658	1554	**2830**	5126
449	**840**	1544	588	**1090**	1994	727	**1340**	2444	860	**1580**	2876	1004	**1840**	3344	1143	**2090**	3794	1282	**2340**	4244	1416	**2580**	4676	1560	**2840**	5144
454	**850**	1562	593	**1100**	2012	732	**1350**	2462	866	**1590**	2894	1010	**1850**	3362	1149	**2100**	3812	1288	**2350**	4262	1421	**2590**	4694	1566	**2850**	5162
460	**860**	1580	599	**1110**	2030	738	**1360**	2480	871	**1600**	2912	1016	**1860**	3380	1154	**2110**	3830	1293	**2360**	4280	1427	**2600**	4712	1571	**2860**	5180
466	**870**	1598	604	**1120**	2048	743	**1370**	2498	877	**1610**	2930	1021	**1870**	3398	1160	**2120**	3848	1299	**2370**	4298	1432	**2610**	4730	1577	**2870**	5198
471	**880**	1616	610	**1130**	2066	749	**1380**	2516	882	**1620**	2948	1027	**1880**	3416	1166	**2130**	3866	1304	**2380**	4316	1438	**2620**	4748	1582	**2880**	5216
477	**890**	1634	616	**1140**	2084	754	**1390**	2534	888	**1630**	2966	1032	**1890**	3434	1171	**2140**	3884	1310	**2390**	4334	1443	**2630**	4766	1588	**2890**	5234
482	**900**	1652	621	**1150**	2102	760	**1400**	2552	893	**1640**	2984	1038	**1900**	3452	1177	**2150**	3902	1316	**2400**	4352	1449	**2640**	4784	1593	**2900**	5252
488	**910**	1670	627	**1160**	2120	766	**1410**	2570	899	**1650**	3002	1043	**1910**	3470	1182	**2160**	3920	1321	**2410**	4370	1454	**2650**	4802	1599	**2910**	5270
493	**920**	1688	632	**1170**	2138	771	**1420**	2588	904	**1660**	3020	1049	**1920**	3488	1188	**2170**	3938	1327	**2420**	4388	1460	**2660**	4820	1604	**2920**	5288
499	**930**	1706	638	**1180**	2156	777	**1430**	2606	910	**1670**	3038	1054	**1930**	3506	1193	**2180**	3956	1332	**2430**	4406	1466	**2670**	4838	1610	**2930**	5306
504	**940**	1724	643	**1190**	2174	782	**1440**	2624	916	**1680**	3056	1060	**1940**	3524	1199	**2190**	3974	1338	**2440**	4424	1471	**2630**	4856	1616	**2940**	5324
510	**950**	1742	649	**1200**	2192	788	**1450**	2642	921	**1690**	3074	1066	**1950**	3542	1204	**2200**	3992	1343	**2450**	4442	1477	**2630**	4874	1621	**2950**	5342
516	**960**	1760	654	**1210**	2210	793	**1460**	2660	927	**1700**	3092	1071	**1960**	3560	1210	**2210**	4010	1349	**2460**	4460	1482	**2700**	4892	1627	**2960**	5360
521	**970**	1778	660	**1220**	2228	799	**1470**	2678	932	**1710**	3110	1077	**1970**	3578	1216	**2220**	4028	1354	**2470**	4478	1488	**2710**	4910	1632	**2970**	5378
527	**980**	1796	666	**1230**	2246	804	**1480**	2696	938	**1720**	3128	1082	**1980**	3596	1221	**2230**	4046	1360	**2480**	4496	1493	**2720**	4928	1638	**2980**	5396
532	**990**	1814	671	**1240**	2264	810	**1490**	2714	943	**1730**	3146	1088	**1990**	3614	1227	**2240**	4064	1366	**2490**	4514	1499	**2730**	4946	1643	**2990**	5414
538	**1000**	1832	677	**1250**	2282				949	**1740**	3164	1093	**2000**	3632	1232	**2250**	4082				1504	**2740**	4964	1649	**3000**	5432
									954	**1750**	3182										1510	**2750**	4982			

To convert Fahrenheit into centigrade: Subtract 32 from Fahrenheit, divide remainder by 9, and multiply by 5.
EXAMPLE: 212°F. 212 − 32 = 180. 180 ÷ 9 = 20. 20 × 5 = 100. Ans. 212°F. = 100C°.
Centigrade to Fahrenheit: Divide by 5, multiply by 9, and add 32.
Example: 260°C. ÷ 5 = 52. 52 × 9 = 468 + 32 = 500°F. Ans. 260°C. = 500°F.

INTERPOLATION FACTORS

C.		F.	C.		F.
0.56	**1**	1.8	3.33	**6**	10.8
1.11	**2**	3.6	3.89	**7**	12.6
1.67	**3**	5.4	4.44	**8**	14.4
2.22	**4**	7.2	5.00	**9**	16.2
2.78	**5**	9.0	5.56	**10**	18.0

Salt Baths

Sometimes used for high-speed steel. They permit rapid cooling to bath temperature and slower rate to room temperature. Must be finally cooled below 200°F and drawn as in other cooling methods.

TABLE 4.—FIXED POINTS FOR THERMOMETER CALIBRATION COMMONLY USED IN THE HEAT-TREATING DEPARTMENT

Substance	Point	Temperature	
		Thermo, °F.	Scale, °C.
Alcohol, ethyl	Boils	173.0	78.3
Aluminum (Al), pure metal	Melts	1218.0	658.7
Antimony (Sb), pure metal	Melts	1166.0	630.0
Barium (chloride) ($BaCl_2$) salt	Melts	1760.0	960.0
Benzene	Boils	176.0	80.0
Cadmium (Cd), pure metal	Melts	624.2	320.9
Cobalt (Co), pure metal	Melts	2696.0	1480.0
Copper (Cu), pure metal	Melts	1983.0	1083.0
Glycerine	Boils	554.0	290.0
Gold (Au), pure metal	Melts	1945.4	1063.0
Iron (Fe), pure metal	Melts	2912.0	1600.0
Lead (Pb), pure metal	Melts	620.0	327.0
Mercury (Hg), pure metal	Solidifies	173.0	78.5
Mercury (Hg), pure metal	Boils	675.0	357.3
Nickel (Ni), pure metal	Melts	2645.6	1452.0
Platinum (Pt), pure metal	Melts	3191.0	1755.0
Potassium nitrate (KNO_3) salt	Melts	642.0	337.0
Silver (Ag), pure metal	Melts	1769.0	960.5
Sodium chloride (NaCl) salt	Melts	1481.0	805.0
Sodium nitrate ($NaNO_3$) salt	Melts	593.6	312.0
Sodium sulphate (Na_2SO_4) salt	Melts	1623.2	884.0
Sulphur (S), amorphous	Boils	833.0	444.7
Tin (Sn), pure metal	Melts	450.0	232.0
Tungsten (W), pure metal	Melts	7052.0	3400.0
Water, distilled	Boils	212.0	100.0
Zinc (Zn), pure metal	Melts	786.2	419.0
Lead, 35% Tin, 65% lowest melting alloy of these two metals	Melts	358.0	181.0
Sodium chloride, 45% Sodium sulphate, 55% lowest melting mixture of these two salts	Melts	1154.0	623.0
Sodium nitrate, 50% Potassium nitrate, 50% lowest melting mixture of these two salts	Melts	424.0	218.0

Air Quenching

Air cooling, recommended for some highly alloyed steels, requires a free circulation of air past the steel. A fan blast accelerates cooling. *Dry* compressed air is sometimes used to cool parts of the steel rapidly. Moisture in air may crack the steel.

Do not temper (or draw) tool steel until it has cooled so it can be handled. But do not let it get really cold before drawing. Keep it warm if necessary, in warm quenching oil.

TABLE 5.—DRAWING BATH MIXTURES
For names of salts designated, see Table 4

Material		Melting Temperature	Range, °F.	Remarks
67 % $NaNO_3$	33 % KNO_3	450	500–1000	
50 % $NaNO_3$	50 % $NaNO_2$	350	355–1000	
100 % NaCl	....	1510	1515–1830	Fumes destructive to fire clay
	100 % Na_2SO_4	1535	1545–1830	Na_2SO_4 destructive—use metal pots
77 % NaCl	23 % Na_2SO_4	1340	1350–1830	Fumes not to come in contact with fire clay
50 % NaCl	50 % Na_2SO_4	1157	1170–1650	Lowest melting salt mixture
27 % NaCl	73 % Na_2SO_4	1365	1375–1740	Not corrosive to metal
100 % KNO_3	....	650	655–1200	Decomposes before boiling
	100 % $NaNO_3$	590	600–1200	Do not overheat
78 % KNO_3	22 % $NaNO_3$	490	500–1290	Good temper bath
54 % KNO_3	46 % $NaNO_3$	430	435–1200	Lowest melting salt mixture
23 % KNO_3	77 % $NaNO_3$	545	555–1200	Overheating breaks up salt
100 % Sb	....	1170	1180–1470	Cover metal with charcoal
	100 % Pb	620	630–1290	Oxidizes rapidly if overheated
35 % Sb	65 % Pb	750	760–1290	Good for normalizing
13 % Sb	87 % Pb	475	485–1290	Lowest melting alloy
55 % Sb	45 % Pb	930	945–1380	Lighter in weight than lead

A very good table from which to make up baths for drawing the temper follows. See Table 6.

Sodium cyanide is now used in place of potassium cyanide where only a thin skin of hardening, or light case, is desired. It is much less expensive than potassium cyanide and equally effective.

HARDNESS AND TENSILE STRENGTH

As some hardness specifications refer to tensile strength instead of the Brinell or Rockwell numbers, the table on page 1057 will be found useful in making comparisons.

Table 6.—Other Baths for Drawing Carbon Tools

Composition of Bath Lead and Tin		Melting Point in Degrees Fahrenheit	Color of Steel at Temperature Given	Good Temper for Carbon Steel
14	8	420	Very faint yellow	
15	8	430	Faint yellow	
16	8	440	Light straw	
17	8	450	Straw	Drills, taps, dies, reamers, punches, and shear blades
18.5	8	460	Full straw	
20	8	470	Dark straw	
24	8	480	Old gold	
28	8	490	Brown	Cold chisels, large punches, beading and calking tools
38	8	510	Brown with purple spots	
60	8	530	Purple	
96	8	550	Deep purple	Smith's tools, swages, hot and cold cutters
200	8	560	Blue	
Boiling linseed oil		600	Dark blue	Boiler snaps or sets, stamping and pressing dies
Melted lead		610	Gray blue	

These are used in a similar manner to the hardening baths, selecting the bath which gives the proper drawing temperature.

USES OF CARBON TOOL STEELS[1]

Carbon—0.60 to 0.70.—Use where a keen edge is not necessary, as for:

- Brick chisels
- Drop hammer dies
- Gardening tools
- Granite wedges
- Pick points
- Rivet sets
- Setscrews
- Tongs
- Valve links
- Key steel

Forge at 1600°F. Harden at 1410 to 1450°F.

Carbon—0.70 to 0.80.—Combines toughness with considerable degree of hardness. Use for:

- Anvil faces
- Blacksmiths' hammers and tools
- Bucket teeth
- Cold chisels
- Logging tools
- Mining drills
- Pneumatic hammer tools
- Shear blades (large)
- Tongs
- Wrenches
- Rivet sets

Forge at 1600°F. Harden at 1400 to 1440°F.

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[1] The Midvale Company.

Carbon—0.80 to 0.90.—Combines toughness with hardness. Use for:

- Ball peen hammers
- Beading tools
- Cruciform drill steel
- Hand chisels
- Hot chisels
- Punches
- Pneumatic hammers
- Cylinders
- Quarry drills
- Shear blades
- Spring steel
- Vise jaws

Forge at 1600°F. Harden at 1390 to 1430°F.

Carbon—0.90 to 1.00.—Combines hardness with toughness. Use for:

- Cant dogs
- Cold heading dies
- Forming, punching, and trimming dies
- Machinists' hammers
- Pocket knife blades
- Shear blades (small)
- Spring steel

Forge at 1600°F. Harden at 1390 to 1430°F.

Carbon—1.00 to 1.10.—For tools in which hardness is prime consideration. Examples:

- Axe bits
- Collets
- Coining dies
- Flat drills
- Lathe centers
- Molders' tools
- Scythe edges

Forge at 1600°F. Harden at 1390 to 1430°F.

Carbon—1.10 to 1.20.—For use where hardness is prime consideration. Examples:

- Ball bearings
- Cold cutting dies
- Drawing dies
- File cutting chisels
- Flat or twist drills
- Lathe and planer tools
- Reamers
- Silversmiths' dies
- Taps
- Plug drills
- Woodworking knives

Forge at 1500°F. Harden at 1385 to 1430°F. Small tools should be treated in oil.

Carbon—1.20 to 1.30.—Tools for which hardness or a keen cutting edge is necessary. Examples:

- Brass turning tools
- Cabinet files
- File cutting chisels
- Granite chisels and points
- Reamers
- Stone planing tools
- Wire drawing dies
- Wood turning tools

Forge at 1500°F. Harden at 1385 to 1430°F. Small tools should be treated in oil.

Carbon—1.30 to 1.40.—For use where a keen edge is of prime importance. Examples:

- Boring and finishing tools
- Cutters
- Wire drawing dies

Forge at 1500°F. Harden at 1385 to 1425°F. Small tools should be treated in oil.

Heat-Treatment

Annealing.—Carbon tool steel to be annealed should be heated uniformly and slowly to 1400°F., and not in direct contact with the fire. It should then be buried in air-slaked lime, dry sand, fine ashes, or other poor conductor of heat. If the pieces are small, the covering material should be heated, or they can be placed while hot between two pieces of pine wood and buried as previously stated. Do not remove until cold. If the forgings are thick-walled or of complicated shape, the best practice after rough machining is to quench them in oil from a temperature slightly above the critical point and temper them below the critical range, at about 1250°F. Final hardening can then be done without distortion.

Hardening.—Heating for hardening must be uniform, the degree to be governed by the carbon in the metal. High-carbon steel is heated to a lower temperature than low-carbon steel. If tool steel is slightly overheated, let it cool down to a black condition and reheat for hardening; never let it cool to the proper temperature and then quench. Intricate sections are often hardened in oil, and it may be necessary to go from 50 to 100 degrees above the hardening temperature proper for water.

TABLE 7.—TEMPERING TABLE

Temperature for 1 Hour		Color	Temperature for 8 Minutes		Suggested Uses
F.	C.		F.	C.	
370	188	Faint yellow	460	238	Scrapers, brass turning tools, reamers, taps, milling cutters, saw teeth
390	199	Light straw	510	265	Twist drills, lathe tools, planer tools, finishing tools
410	210	Dark straw	560	293	Stone tools, hammer faces, chisels for hard work, boring cutters
430	221	Brown	610	321	Trepanning tools, stamps
450	232	Purple	640	337	Cold chisels for ordinary work, carpenters' tools, picks, cold punches, shear blades, slicing tools, slotter tools
490	254	Dark blue	660	349	Hot chisels, tools for hot work, springs
510	265	Light blue	710	376	Springs, screw drivers

NOTE.—It will be noted that two sets of temperatures in Fahrenheit and centigrade degrees are shown, one being specified for a time interval of 8 minutes, the other 1 hour. Articles to be tempered should be placed in the bath, the temperature then being brought up to that shown in the table and held for the time required. This method gives results far superior to the old, and the long draw at the lower temperature will put the steel in the best condition of all.

HIGH-SPEED STEELS

These steels are made by alloying tungsten, chromium, molybdenum, vanadium, and other alloys with steel. These compositions completely revolutionize the points of transformation. Chromium, which has a tendency to raise the critical temperature when added to a tungsten steel in the proportion of 1 or 2 per cent, reduces the critical temperature to below that of the atmosphere. Tungsten and molybdenum prolong the critical range of temperatures of the steel on slow cooling so that it begins at about 1300°F. and spreads out all the way down to 600 degrees.

These steels are heated to 1850 degrees for the molybdenum and 2350 degrees for the tungsten and are cooled moderately fast, usually in an air blast, to give them the property known as "red-hardness." This treatment prevents the critical changes altogether and preserves the steel in what is known as the "austenitic condition." The austenitic condition is one of hardness and toughness.

One rule which has given good results in heat-treating these high-speed steels is to heat slowly to 1500°F., then heat fast to 2350°F.; after which, cool rapidly in an air blast to 1550°F.; then cool either rapidly or slowly to the temperature of the air. Others advocate cooling in crude oil.

Commonly used high-speed steels are known as 18-4-1 and 18-4-2, composed of 18 per cent tungsten, 4 per cent chromium, and 1 or 2 per cent vanadium. In some 18-4-1 steels from 5 to 12 per cent of cobalt is added.

ALLOY-STEEL DEVELOPMENT

Alloy steels have been developed to meet the needs of modern industry which required tougher, stronger, and harder steels than can be obtained in simple carbon steels. The growth of the automobile has been made possible by this development, which, in turn, came to meet the needs of the automobile builders. The alloy steels vary widely in kind of alloy and in the proportion of alloy and of carbon content. The special alloy should be chosen to suit the particular requirements of each special case, although there

Ingredient	Its Effect
Iron	The basis of all steel.
Carbon	The determinative.
Sulphur	The strength sapper.
Phosphorus	The weak link.
Oxygen	A strength destroyer.
Manganese	Adds strength.
Nickel	Adds strength and toughness.
Tungsten	Hardener and heat resister.
Chromium	For resisting shocks.
Vanadium	Purifier and fatigue resister.
Silicon	Impurity and hardener.
Titanium	Removes nitrogen and oxygen.
Molybdenum	Hardener and heat resister.
Aluminum	Kills or deoxidizes steel.

are, of course, several alloy steels which will satisfactorily cover a large variety of requirements. It must be remembered, however, that no alloy steel is a universal steel and best for all purposes.

The making of alloy steel requires care since much of its value depends upon its being uniform both in physical and in machining qualities.

The various ingredients of alloy steels may be summed up in the working of steel as shown in the table on page 1030.

Functions of Different Elements

We can sum up the different elements in ordinary alloy steels to have the following functions: carbon for hardness and rigidity; manganese for toughness; silicon as a sort of adjuster; sulphur and phosphorus as lubricants; chromium as a refiner of grain and to add hardness to help carbon; nickel as a protecting support of structure and as an aid to stability; and vanadium in small doses to act as a scavenger—in high percentage it is a great resister of friction.

In heat-treating alloy steel there are certain factors to bear in mind. These factors may vary slightly as to the duration of heat limits, but they are always present, and the following points must be considered:

1. We must know the critical points.
2. We must not fall below high critical point when soaking steel.
3. Steel of the same analysis must have the same length of time for soaking to give uniform results.
4. Quenching must be done within certain limits of temperature, depending on the quality of the work performed, or uniform results cannot be obtained.
5. Tempering heats vary on a 10°F. basis; very close heat limits must be established for the quality of work desired.
6. A low limit must be set as to the time necessary for soaking at high heat. This heat must not fall below the heat wanted while being soaked, for if it does, the timing must begin when this temperature is again reached. Too long soaking may cause a reaction, giving a dry steel with a great drop in elastic strength.
7. When taken out of the furnace, the work should be buried in lime and thoroughly covered with no chance for air pockets. Air-cooled steel will contain hard spots on the surface and soft spots in the interior. If no information is at hand as to the critical points of steel, they can very easily be ascertained by pyrometer or magnet methods.

Critical Temperatures of Steel

The critical temperatures of steel in heating and in cooling are very important. These are called "calescent" and "recalescent" and are found by careful use of the pyrometer. The calescent point can be determined by use of the pyrometer by closely watching its needle. The thermocouple, or fire end, should be inserted in the steel. Drill a hole in the piece to take in the fire end of the thermocouple. As the heat advances, the needle will follow until it reaches a point where it suddenly stops, wavers, and then suddenly drops several degrees, although the heat is constantly advancing; then the needle will again suddenly commence its upward swing. Where the needle stops its upward swing and rests is the calescence, or low critical, point.

Now reverse the operation. Heat beyond the critical point and shut off the fuel and watch for the same phenomena. The needle will fall with heat, suddenly stop, then advance several degrees, when it again starts to drop for good. This upper change is called the "recalescence" point.

You can also test with an ordinary horseshoe magnet. Touch the steel with a magnet during heating, and the temperature at which the steel fails to attract the magnet or, in other words, loses its magnetism is the point of calescence, or critical point.

Even Heating Necessary

Strains in steel are very often caused by having no heat circulation about the work, particularly when heating in furnace, by work being placed on the furnace floor. Circulation of heat is necessary, and the best method is to lay long pieces or strips on raised perforated platforms.

The furnace should be "balanced"; in other words, the heat must be evenly distributed; in fact, several firing ends should be in the furnace at all times, connected by a switch to the same pyrometer.

The cooling agent should also be kept within very close temperature limits.

Colors of Heated Steel in Diffused Daylight

The following list of colors is given by the Vanadium Corporation of America:

Colors	Degrees Fahr.
Dark blood red or black red	990
Dark red, blood red or low red	1050
Dark cherry red	1175
Medium cherry red	1250
Cherry, full red	1375
Light cherry, bright cherry, *scaling heat	1550
Salmon, orange, free scaling heat	1650
Light salmon, light orange	1725
Yellow	1825
Light yellow	1975
White	2200

* Scaling heat: Scales just form but do not fall away when cooling.

English Suggestions on Hardening High-Speed Steel

The Sheffield Twist Drill and Steel Company, Ltd., very large users of high-speed steels, give general directions as follows:

Forging.—Heat the steel as slowly as possible to 850°C., and then fairly rapidly to a temperature of 1050 to 1100°C., ensuring even heat before working. Care must be taken not to work the steel below a red heat or 850°C.

Annealing.—Heat slowly to a temperature of 850 to 900°C., and maintain this heat until the steel is uniformly heated throughout. Then allow the steel to cool down very slowly inside the furnace.

Hardening.—Preheat slowly to 850 to 900°C., then raise the heat rapidly to 1250 to 1300°C. Quench in air or oil.

Tempering or Secondary Treatment.—After the steel is cooled from hardening, reheat to a temperature of 560 to 610°C. It is of the utmost importance that the tempering temperature should be within the above range.

Magnetic Superhardening

Edward G. Herbert of England has found that steel may be superhardened by placing the hardened surface across the poles of a powerful electromagnet, tapping it lightly, and turning the piece to different angles. This is particularly effective in steel that has been surface-hardened by the cloudburst method. It is not known to what extent this method has been put into practical use.

Cloudburst Hardening

This method of raining balls on a metal surface is also used to harden it by the cold-working process. The drop is so adjusted as to just mark the surface and the piece subjected to a rain of blows for a short period till the surface is thoroughly cold-worked. The height of the drop is then increased and the process repeated to promote hardening without damage to the metal. This is repeated until desired results are secured.

STELLITE

Stellite was originated and developed by Elwood Haynes. It is composed principally of cobalt and chromium with a small amount of tungsten. It is not a steel, as it contains practically no iron.

One of the most remarkable properties of stellite is its ability to retain a cutting edge at high temperatures. This permits higher cutting speeds than are possible with steel tools. Stellite tools are made in different grades for various kinds of work. Tools are cast close to size and finished by grinding. Turning tools are made by brazing stellite tips on steel shanks, which should be large enough to prevent springing. In milling cutters, stellite teeth are held in a steel body and should be well supported. Stellite tools work equally well when hot. Sudden cooling causes checks and should be avoided.

The quality of red-hardness makes stellite particularly useful for wearing surfaces subjected to high temperature. Inserts having a face of stellite are being used for valve seats in internal-combustion engines.

Chip wear on boring bars and tool blocks can be greatly reduced by applying stellite or other wear strips near the cutters to prevent chips from cutting the bar.

TABLE 8.—CARPENTER STAINLESS STEELS

Group A	Group B	Group C
Analysis: Groups A and B are primarily straight chromium steels. Multiply the percentage of carbon in the steel by 17. Subtract this from the percentage of chromium in the steel. If the result is less than 12.5 per cent, it is Group A; if greater than 12.5 per cent, it is Group B. Either group may contain small percentages of copper, nickel, silicon, molybdenum, sulphur, etc., for special purposes		Contains at least 24 per cent of chromium and nickel combined. Neither chromium nor nickel should be less than 8 per cent. May contain small percentages of other elements for special purposes
Magnetic Properties: This group is magnetic	This group is magnetic	This group is nonmagnetic
Heat Treatment: Respond to hardening and tempering like ordinary steels. Resulting physical properties depend largely on carbon content	Do not respond to hardening by heat-treatment	Do not respond to hardening by heat-treatment
Toughness: Are structurally dependable. Are not brittle in sharp-notched sections or under impact	Have low impact resistance in notched sections	Extremely tough at all times. Thoroughly dependable for any type of shock service within the capacity of their strength
Grain Growth at High Temperatures: Not subject to excessive grain growth at elevated temperatures. Remain tough at all temperatures up to 1400°F.	Prolonged exposure to elevated temperatures usually causes excessive grain growth and brittleness	Grain growth is rapid above 1800°F. Caution must be used for operating temperatures between 800 and 1500°F.
Hot-working Properties: Readily forged, pierced, or rolled	Readily forged, pierced, or rolled	Readily forged, pierced, or rolled
Air Hardening: This group air-hardens from above 1500°F.	Do not appreciably air-harden	Do not air-harden at all
Cold-working Qualities: Can be cold-drawn into wire, cold-rolled, bent, formed, upset, coined, and deep-drawn	Can be cold-drawn into wire, cold-rolled, bent, formed, upset, coined, and deep-drawn	Can be cold-drawn into wire, cold-rolled, bent, formed, upset, coined, and deep-drawn. Work harden twice as rapidly as Groups A and B

TABLE 8.—CARPENTER STAINLESS STEELS—(*Continued*)

Group A	Group B	Group C
Machinability: Machine satisfactorily with properly designed tools. High-sulphur types machine like Bessemer screw stock	Machine satisfactorily with properly designed tools	Difficult to machine. Become free-machining when sulphur or selenium is added to the analysis
Riveting: Make excellent cold rivets. Not recommended for hot rivets driven above 1500°F. on account of air-hardening	Owing to low impact values, special precautions are necessary when used for rivets	Excellent for either hot or cold rivets. Hot rivets should be heated all over to at least 1800°F.
Welding: Can be welded with gas, electric arc, or resistance. Weld air-hardens. No grain growth. Free-machining types are not recommended for welding	Can be welded with gas, electric arc, or resistance. Grain growth and brittleness may result	Easiest group to weld. Welds are tough. Corrosion resistance may be badly damaged by welding. Free-machining types are not recommended for welding
Corrosion Resistance: Very satisfactory for resisting weather, water, and some chemicals	Better than Group A	Better than steels of equal chromium content in Group B
Scale Resistance: Recommended for continuous service up to 1200°F.	Better than Group A. Useful temperature increases with the percentage of chromium	Better than steels of equal chromium content in Group B
Strength at High Temperatures: Has better strength than carbon steel up to 1200°F.	Better than Group A	Best steels available are of this group

Stellite is also used for facing the cutting edges of dredge buckets and other implements subject to wear from abrasion. Metal-cutting shear blades are also faced with stellite to increase the wear life. In such cases the facing material is usually deposited by the oxyacetylene process, using a flame with an excess of acetylene.

COBALT TOOLS

In forging high-cobalt steel it must be heated slowly to a scaling heat, lemon color, 1800 to 2100°F. Forging at too low a heat causes cracks. With the shank and the tip machined ready to braze, the tip should be slowly preheated to about 1500°F. then put in the heating furnace and brought up quickly to 2300 or 2375°F., brazing the tip at the same time. Cool it in air to about 220 degrees and draw immediately to 750 to 850 degrees for at least an hour after the steel has reached this temperature. From $\frac{1}{8}$ to $\frac{1}{16}$ inch must be ground from the cutting profile to remove the decarburized surface. This must be done wet, with a fast cutting wheel, as heating the tip in grinding produces cracks.

Stainless Steel

Stainless steel contains chromium of at least 12 per cent and up to 30 per cent in Type 446 of Republic Steel Corporation. The name "stainless" was originally patented by the Firth Company of England, but similar steels are made with other trade names. It is used for turbine blades, cutlery, thin sheets for airplanes, and other uses where resistance to corrosion is important. Care must be used in forging to prevent stresses due to unequal cooling. High

TABLE 9.—TYPICAL HEAT-TREATMENT OF STAINLESS STEELS

Brand Name	Type Analysis				Forging Heats, Heats, Degrees Fahrenheit	Annealing Treatment, Degrees Fahrenheit	Hardening Treatment, Degrees Fahrenheit	Drawing Range
	C.	Cr.	Ni.					
Carpenter Stainless No. 1	0.10	11.50 to 13.00	....	....	2100 cool in air	1350 cool in air	1700 to 1800 quench in oil	400 to 1300
Carpenter Stainless No. N-1	1.10	13.00	2.00					
Carpenter Stainless No. 2	0.30 in	13.00	....	....	2100 cool slowly	1450 cool in furnace	1825 quench in oil	300 to 400
Carpenter Stainless No. 2-B	1.00	17.00	....	....	2000 cool slowly	1600 cool in furnace	1900 quench in oil	300 to 400
Carpenter No. 3	0.30	20.00	....	Cu 1.00	2100 cool slowly	1550 cool in furnace	Will not harden	
Carpenter Stainless No. 4	0.10	18.00	9.00	....	2100 cool in air	1800 to 2100 quench in water	Hardens only by cold work	
Carpenter Stainless No. 5	0.10	14.00	....	S 0.30	2100 cool in air	1300 cool in air	1825 quench in oil	400 to to 1300
Carpenter Stainless No. 6	0.10	17.00	....	....	2100 cool in air	1350 cool in air	Will not harden	
Carpenter Stainless No. 8	0.10	18.00	9.00	Se 0.25	2100 cool in air	1800 to 2100 quench in water	Hardens only by cold work	

polish helps to resist corrosion. It is made in various grades to suit different requirements, some grades being easily machined.

Forging of stainless steel is done at about 2100°F., cooled slowly in air. Annealing temperatures recommended by Carpenter Steel Company vary from 1300 to 2100°F., depending on the amount of chromium, 1350 to 1500°F. being more common. Some of these steels will not harden. Others heated from 1700 to 1900°F. will harden in oil. Drawing temperatures vary from 400 to 1300°F. Pack hardening is not recommended. Stainless steel can be melted except in open fire, and also brazed and soldered.

Chromium is added to steel to make it nonrustable by weather. Other elements are added for various reasons, but all stainless steels, according to the Carpenter Steel Company, fall into three groups which are called A, B, and C. The characteristics of these steels are tabulated, as are suitable heat treatments, in Table 8.

Highly polished steel of any kind resists corrosion better than a rough surface.

Annealing Temperatures

STAINLESS STEELS	TEMPERATURE
10 to 13 per cent chrome......	Heat to 1650°F.; furnace cool to 1100°F.
14 to 23 per cent chrome......	Heat to 1450 to 1500°F.; air cool
.10 per cent carbon—18 per cent chrome (known as 18-8)....	Heat to 1900 to 2100°F.; cool rapidly

Stainless steels are made in various grades. Some will not harden, others only harden by cold-working. Several harden by heating from 1700 to 1900°F. and quenching in oil. Makers instructions should be followed.

Heat-Treatment of Spring Steel

The following heat-treatment for springs has been recommended by the American Society of Steel Treaters. The steels referred to

HEAT-TREATMENTS FOR LEAF AND COIL SPRINGS

Steel	Normalizing Tempera-ture, Degrees Fahr.	Hardening Tempera-ture, Degrees Fahr.	Approxi-mate Tempering Tempera-ture, * Degrees Fahr.	Brinell Hardness Number
C..............	1575–1625	1525	600–950	352–415
Cr.............	1600–1650	1525	650–950	363–444
CrV............	1600–1675	1550–1600	675–975	363–444
CrMo...........	1600–1675	1550–1600	675–975	363–444
CrSiMn.........	1600–1650	1600–1650	675–975	363–444
SiMn...........	1600–1650	1600–1650	650–950	363–444

* The tempering temperatures are to be used only as a guide in obtainin- the Brinell hardness numbers given in the table.

are C, carbon; Cr, chromium; CrV, chrome-vanadium; CrMo, chrome-molybdenum; CrSiMn, chrome-silicon-manganese; SiMn, silicon-manganese.

The steel is normalized when considerable machining is required, when severe cold-working is to be done or when the product has been subjected to localized heating at several places for the purpose of forging. The normalizing temperatures are given in the table on page 1037.

CARBURIZING

Case hardening, carbonizing or carburizing, is largely used so that the outer shell can be made hard enough to resist wear, while the core of the piece can be left soft enough to withstand the shock strains to which it is subjected.

Case hardening is, in reality, the quenching of the metal after its surface has absorbed carbon so that it hardens on being quenched suddenly. Generally speaking, carbon is absorbed from bone, leather or similar materials, while the low-carbon steel is properly packed and heated. Another method allows the carbon to be absorbed from gas instead of from solid materials.

The result of the carburizing operation is determined by five factors, which are as follows: First, the nature of the steel; second, the nature of the carburizing material; third, the temperature of the carburizing furnace; fourth, the time the piece is submitted to the carburizing process; fifth, the heat-treatment which follows carburizing.

If the steel used has a carbon content up to 56 points, the rate of penetration in carburizing is practically constant; but the higher the carbon content is in the core, the more brittle it becomes by prolonged annealing after carburizing. Therefore, it is necessary that the carbon content should be low in the core, and for this reason a preference is given to steels containing from 15 to 20 points of carbon for carburizing or case-hardening purposes and the carbon brought up to 80 or 85 points. Tool steels may be carbonized up to 250 points, a point is 0.01 of 1 per cent.

Manganese, chromium, tungsten, and molybdenum increase the rate of penetration. Nickel, silicon, titanium, and aluminum retard the rate of penetration—5 per cent of silicon reducing it to zero.

The Carburizing Materials

The nature of the carburizing materials has an influence on the speed of penetration, and it is very essential that the materials be of a known chemical composition, as this is the only way to obtain like results on the same steel at all times.

These materials or cements are manufactured in many special and patented preparations. The following materials are used and compounded in these preparations, but many of them give as good results when used alone as when compounded with others in varying percentages: powdered bone; wood charcoal; charred sugar; charred leather; potassium cyanide; potassium ferrocyanide; bichromate; animal black, acid cleaned; prussiate of potash potassium; anthracite; mixture of barium carbonate; graphite; petroleum gas; acetylene; horn; etc.

Sodium cyanide is being used in place of potassium cyanide as it is much cheaper. The following mixture makes a cheap and efficient case-hardening bath: sodium cyanide, 3 pounds; sodium chloride (common salt), 3 pounds; and soda ash, 4 pounds.

Wood charcoal is very largely used in carburizing steels, but the value of this material varies with the wood used, the method employed in making the charcoal, and other factors. Used alone it gives the normal rate of penetration for the first hour, but after that the rate gradually decreases until at 8 hours it gives the lowest rate of penetration of any of the carburizing materials. The best wood charcoal is that made from hickory.

Powdered charcoal and bone give good results as a carburizing material and are successfully used in carburizing nickel-chrome steel by packing in a pot and keeping at a temperature of about 2000°F. for 4 hours, and then cooling slowly before taking out the pot or uncovering it. Pots are made of cast iron, nichrome, or other heat-resisting alloys.

The General Motors Company specifies that carburizing material be made from charcoal, coke, and carbonate energizers. Hardwood charcoal must be used, and it must pass through a ⅜-inch sieve, but not through a ⅛-inch mesh. Coke is of Solvay process or equivalent and of same size as charcoal.

Two compositions are used:

	G. M. C. 2002 M	G. M. C. 2001-M
Coke	Not over 25 per cent	Not over 25 per cent
Sodium carbonate	3 to 5 per cent	8 to 12 per cent
Calcium carbonate	3 to 5 per cent	
Barium carbonate	5 to 7 per cent	
Total sulphur	Not over 0.5 per cent	Not over 0.25 per cent
Moisture	Not over 4 per cent	Not over 6 per cent
Charcoal and binder	Balance	Balance
Inorganic matter, exclusive of carbonates	Not over 8 per cent	

Not less than 97 per cent of mixture must pass through a 0.371-inch opening, and not over 5 per cent through a 0.131-inch screen. The shrinkage by volume shall not be over 25 per cent on a 6-hour run at 1700°F.

Automatic Carburizing

Packard has two heat-treating units for automatically carburizing transmission gears and other parts at the rate of 720 sets in 24 hours in each unit. Transmission gears are carburized to a depth of 0.035 to 0.040 inch on the pitch line. Ring gears have an effective case of 0.045 to 0.050 inch on the pitch line. Some are made of S.A.E. 4620 nickel-molybdenum, and others of 3115 chrome-nickel steels. Parts are carburized at 1680°F., and transmission gears are drawn to 435°F.

Temperature in Degrees Fahrenheit for Eight Hours	Materials Used and Rate of Penetration in Inches			
	Charcoal 60 Per Cent + 40 Per Cent of Carbonate of Barium	Ferrocyanide 66 Per Cent + 34 Per Cent of Bichromate	Ferrocyanide Alone	Powdered Wood Charcoal Alone
1300				
1475	0.020	0.033	0.020	0.020
1650	0.088	0.069	0.079	0.048
1825	0.128	0.128	0.128	0.098
2000	0.177	0.177	0.198	0.138

Chapmanizing

Chapmanizing is a process of surface hardening that uses a liquid bath to convey the necessary heat and active nitrogen direct to the metal. Any type of steel, malleable or cast iron, may be surface hardened by this method. Any depth of case from 0.002 to 0.035 inch can be secured. Lower temperatures can be used than in carburizing, and less time is required than by some carburizing methods. A 3-hour heat at 1500°F. gives a 0.030-inch case in S.A.E. 1020 steel.

Colors in Case Hardening

Wrenches and other work of low-carbon steel may be case hardened and at the same time given an attractive coloring or "mottling" by exercising a little care in the process. The work must be perfectly clean and free from grease, and should be nicely polished. Unless this is done, bright colors cannot be secured.

To secure good colors, the bone must be thoroughly charred. This can be done by covering it tightly in iron boxes and placing in the furnace at night or when the heat is going down. If too hot, it will burn instead of charring.

The work should be even more carefully packed than for case hardening without color, leaving more space between the work itself and between the work and the box. The degree of heat and the length of time must, of course, depend on the size of the work, but, generally speaking, a cherry red is correct. The main thing, however, is to maintain an even heat. If the heat is too great, it is impossible to receive a good color or any color.

The work must be dumped without exposing it to the air. It is customary to suspend a sieve beneath the surface of the water in the tank to catch the pieces as they are dumped. The water should be soft for best results and should be kept in motion. There should be sufficient volume, or the water should change often enough to cool the work quickly. A stream of air blowing through the water also helps to agitate it and to secure good coloring. Small lots, of course, do not require so large an amount of water.

The dumping of the work must be carefully done. The box should be held close to the water and dumped quickly. Should the air strike the work before it is quenched, it is almost sure to turn black or blue-black and be streaky.

After cooling, the work is taken out, separated from the bone, and boiled in clean water. It is then dried in sawdust and oiled slightly, which brings out the colors and prevents tarnish.

Further coloring may be done by tumbling the work in a barrel until the work is thoroughly polished. It is then placed over a gas flame or other source of heat and drawn to the desired color, much as we draw the temper on hardened steel. The articles are then plunged in cold water, dried in sawdust, and oiled. Combustion of the fire used must be good, as any gas given off affects the color.

Use of Bone and Charcoal

Case hardening with granulated raw bone is a common practice in many large manufacturing plants. Bone which is hard and flinty, such as that which comes from the skin bones of animals, is considered better than soft, pithy, and greasy bone, as there is no waste. Good bone can be used over and over again by adding fresh stock to it in about the proportion of 1:2 or 1:3. In other words, use two or three parts of old bone to one part of new raw bone.

Raw bone is usually white and burns black when first used. As it loses its carbon, it becomes lighter, and when it burns white, it is of no further value for case hardening. Some raw bone, on the other hand, is quite dark, and only experience with the various materials will make a person familiar with the best mixtures to use for different purposes.

Some case hardeners secure good results and economize on the use of bone by mixing one part of raw bone with three parts of pulverized charcoal. The mixing should be thorough with a little charcoal dust sprinkled over the top.

Where the tendency of case hardened work to scale is objectionable, a thin layer of charred leather next to the work will help to check the scaling.

Carburizing Large Flat Work

The larger the piece, the more bone should be used in packing it for carburizing. With a disc approximately 4 inches thick and 24 inches in diameter, the lower layer of bone should be from 4 to 5 inches thick and the same distance allowed all around the disc. The side to be hardened should be placed down and the top covered to about the same depth as the bottom, the cover then luted in place.

A piece of this size will probably require 8 or 10 hours' soaking at a bright cherry red; it should not be heated above this temperature on account of the increased tendency to warp. This tendency can also be overcome by dipping edgewise into a large body of cold, running water so as to remove the heat quickly. Salt water is also advised in dipping heavy work, as it conducts the heat away more rapidly than fresh water.

Sometimes a mixture of half charcoal and half used bone is used with low-carbon steel. This will not recarburize much more than 5 per cent, or about enough to maintain the original amount of carbon in the steel.

Small or thin iron castings can be annealed by packing in a cast-iron pot or box with a mixture of bright cast-iron turnings or filings and pulverized charcoal. Use about half charcoal and half turnings or filings. Put a layer of the mixture between the castings to prevent warping and to allow them to heat more evenly.

Heat to a cherry red and hold this heat for from 2 to 3 hours. The castings must be left in the pots to cool off.

Sizes of Granulated Bone

The Rogers and Hubbard Company give the following list of sizes of granulated raw bone:

No. 1. Will not pass through smaller than $\frac{1}{4}$ inch square mesh in screen. Best for heavy work.

No. 2. Mesh $\frac{1}{6}$ inch square.

No. 3. Mesh $\frac{1}{8}$ inch square.

Nos. 2 and 3. Best for bicycle, fire arms, sewing machine, and general machine work.

No. 4. Mesh $\frac{1}{12}$ inch square. Good for small work, such as small screws, etc.

No. 5. Smaller than $\frac{1}{12}$ inch. Used only for the very finest work.

NITRIDING STEEL

The nitriding process consists in the subjection of special alloy steels to the action of ammonia gas at a suitable temperature, producing a hard, wear-resistant surface, similar to that produced in case hardening, but more easily obtained and of greater hardness. The surface produced is free of scale, of attractive appearance, and requires no after treatment. Hardening of certain sections only is easily accomplished by any one of several methods.

The steels best suited to case hardening by ammonia are those containing 0.75 to 1.25 per cent aluminum and 1.00 to 1.50 per cent chromium, with 0.20 per cent molybdenum added to give greater toughness to the case and core. These steels are manufactured under the name "Nitralloy" in carbon contents ranging from 0.20 to 0.40 per cent.

Parts to be case-hardened are first machined slightly oversize. They are then heat-treated and afterward machined or ground to the finish size in order to remove the skin of decarburized material and provide a clean surface. They are then placed in a suitable furnace in an atmosphere of ammonia and heated to a temperature of 900 to 1000°F., 975°F. being the most common. They are held in the furnace from 2 to 90 hours, depending on the depth of case desired, and are then cooled in the furnace, the ammonia atmosphere being maintained. Upon removal from the furnace, they are hard and may be put in service without further treatment.

It is necessary to remove all decarburized material from the surface before nitriding. Strains should be removed from all parts to be nitrided by drawing at temperatures equal to or higher than the nitriding temperature. A slight growth, amounting to 0.001 inch or less, takes place on nitriding. The hardness, equivalent to 1000 to 1100 Brinell, is greater than that obtainable by any other treatment. The low temperature used gives low-fuel consumption and easy control, as well as long furnace life. The low temperature also eliminates distortion if the parts are properly drawn before nitriding. Besides great hardness, the nitride case shows remarkable resistance to corrosion.

CASE-HARDENING CAST IRON

A bath recommended for hardening cast iron for various reasons, such as gaging or locating points, is made up of 16 ounces of sulphuric acid, 1 ounce of nitric acid, and 1½ gallons of water. The piece is heated to a bright red and quenched in the mixture.

SELECTING THE PROPER TEMPERATURE FOR QUENCHING

A hardening process that will produce a steel that is as homogeneous as possible is always sought for in practice. This is easily obtained in a high-carbon steel, and especially if it contains 85 points carbon, by passing the recalescent point before quenching. The desired homogeneity is not so easily obtained, however, in the low-carbon steels, as they have several points of transformation. If these are quenched at a point a little above the lowest point of transformation, the carbon will pass into solution, but the solution is not homogeneous. To obtain this result it is necessary that the quenching be done from a little above the highest point of transformation. This is higher in the low- than in the high-carbon steels. In practice, this calls for a quenching of the low-carbon steels at about 1650°F., while a high-carbon steel should be quenched at about 1450°F.

Testing Pyrometers

Pyrometers can be tested by placing some common salt in an iron box and heating until it melts. Put the pyrometer in the molten salt, and, if correct, it will register 1441°F.

A very convenient table of Fahrenheit and centigrade thermometer scales is given on pages 1023 and 1024.

AUTOMOTIVE STEELS

The engineers of the automobile industry have developed a number of steels and heat-treatments that are equally useful in many other lines of work. These steels are designated by numbers with S.A.E. before them, meaning the steels have been approved and recommended by the Society of Automotive Engineers. The most commonly used steels are given herewith. The uses and heat-treatments follow.

The S.A.E. Numbering System

The S.A.E. Standard System, was developed by the Society of Automotive Engineers, Inc., to provide a simple means of indicating the chemical composition of the various steel grades in more common use. The system is based on the use of numbers composed of four or five digits, and certain letters used as prefixes. The first digit of the standard number indicates the type to which the particular steel belongs. Thus 1 indicates a carbon steel, 2 a nickel steel, 3 a nickel-chromium steel, 4 a molybdenum steel, etc. In the case of the alloy steels, the second digit, and sometimes the third, usually indicates the approximate percentage of the principal alloy; in the case of simple alloys, the alloy from which the steel is named. The final two (sometimes three) digits indicate the mean carbon content in "points," or one-hundredths of 1 per cent. Thus, 2320 indicates a nickel steel of approximately 3 per cent nickel content (3.25 to 3.75 per cent) and 0.20 per cent average carbon 0.15 to 0.25 per cent); 52100 indicates a chromium steel of more than 1 per cent average chromium content (1.20 to 1.50 per cent, as compared with 0.60 to 0.90 per cent or 0.80 to 1.10 per cent for the 5100 series) and 1.00 per cent carbon (0.95 to 1.10 per cent), while 71360 indicates a tungsten steel of 13 per cent tungsten content (12 to 15 per cent) and 0.60 per cent carbon (0.50 to 0.70 per cent).

The prefix X is used in several instances to indicate variations in the range of sulphur, manganese, and chromium, and the prefix T is used with manganese steels to indicate a higher range of manganese than that found in steels of the X1300 series.

Basic numerals of the system are:

Carbon steels—first digit—1:	
Plain carbon	10 ..
Free cutting (screw stock)	11 ..
Free cutting (manganese)	X13 ..
High manganese	T13 ..
Alloy steels—Nickel—first digit—2:	
0.50 per cent nickel	20 ..
1.50 per cent nickel	21 ..
3.50 per cent nickel	23 ..
5.00 per cent nickel	23 .
Nickel-chromium—first digit—3:	
1.25 per cent nickel, 0.60 per cent chromium	31 ..
1.75 per cent nickel, 1.00 per cent chromium	32 ..
3.50 per cent nickel, 1.50 per cent chromium	33 ..
3.00 per cent nickel, 0.80 per cent chromium	34 ..
Corrosion and heat resisting (stainless)	30 ..
Molybdenum—first digit—4:	
Chromium-molybdenum	41 ..
Chromium-nickel-molybdenum	43 ..
Nickel-molybdenum	46 ..
and	48 ..
Chromium—first digit—5:	
Low chromium (up to 1.10 per cent)	51 ..
Medium chromium	52 ..
Corrosion and heat-resisting (stainless)	51 ..
Chromium-vanadium (0.80 to 1.10 per cent chromium)	61 ..
Tungsten	7 ..
and	71 ..
Silico-manganese	9 .

Summary of S.A.E. Steels and Their Uses

S.A.E. steels 1010, 1015, X1015, 1020, and X1020 are carburizing steels for which various heat-treatments are used. A typical treatment is: Carburize at 1650 to 1700°F.; quench direct; temper to 250 or 325°F.

No. 1020.—Used for piston pins, cam shafts, drag links, clutch fingers, etc.

No. 1030.—Machines well and is used for seamless tubing, key stock, shift and brake levers, shift forks, etc. It is quenched in water from 1575 to 1650°F. and tempered to required hardness.

No. 1035.—Largely used for wire and rods for upsetting cold.

No. 1040.—Is also used for tubing and crankshafts, connecting rods, axles, spring clips, brake levers, studs, and similar parts.

No. 1045.—Crankshafts, starter ring gears, axle and spline shafts.

No. 1050.—A medium-carbon steel for larger sections than No. 1045.

No. 1055.—A hard-drawn, oil-tempered wire for general coil spring work.

No. X1055.—Snap rings, cushion springs, lock washers, etc.

No. 1060.—Snap rings, valve springs, cushion springs, clutch springs.

Nos. 1065 and X1065.—For hard-drawn spring wire.

No. 1070.—Cold-rolled or planished for clutch discs and plow beams.

No. 1075.—Agricultural industry for cultivator discs and plows.

No. 1080.—Also agricultural machinery.

No. 1085.—Bumper bars, clutch discs, leaf springs, and mower knives.

Nos. 1090 and 1095.—Carbon steel balls, bumpers, keys, coil springs.

FREE-CUTTING STEELS

No. 1112.—Screw stock; studs, screws and automatic products.

Nos. 1115 and 1120.—Open hearth screw stock. Does not machine so well as No. 1112, but stronger and better for carburized parts. No. 1120 likely to be discarded soon.

Nos. X1314 and 1315.—Good general purpose for carburized parts.

Nos. X1330, X1335, and X1340.—Free-cutting, hardening steels for many purposes.

MANGANESE STEELS

Nos. T1330, T1335, T1340, T1345, and T1350.—Used in same way as other medium-alloy steels with same carbon. Primarily oil-hardening steels and care must be taken in using water.

NICKEL STEELS

No. 2015.—Used as substitute for carburizing carbon steels.

No. 2115.—Carburizing grade of 1½ per cent nickel steel.

No. 2315.—When used for accurate gears, it should be normalized before carburizing to reduce distortion.

No. 2320.—Machines better than No. 2315.

Nos. 2330 and 2335.—Used for strength and toughness, such as keys, heat-treated bolts, studs, and similar parts.

Nos. 2340 and 2345.—Propeller shafts, spline shafts, axles, etc.

No. 2350.—Used primarily for oil-hardened gears.

NICKEL-CHROMIUM STEELS

Nos. 3115 and 3120.—Ring gears, pinions, transmission gears, piston pins.

Nos. 3125 and 3130.—Steering arms, cylinder studs, rod bolts, etc.

Nos. 3135 and 3140.—Crankshafts, axles, spline shafts, etc.

Nos. 3215 to 3250.—For harder service than the No. 3100's.

Nos. 3312 to 3340.—For still harder service than the No. 3200's.

Nos. 3315, 3435, and 3450.—Rear axles and gearing for heavy bus and work truck.

MOLYBDENUM STEELS

Nos. 4130 to 4820.—Used by some for truck and bus work.

CHROME-VANADIUM STEELS

Nos. 6115 to 6195.—Used with various heat-treatments for same parts as other alloy steels with similar carbon content.

Nos. 9255 and 9260.—Silicon-manganese steels mainly for leaf springs.

Nos. 30905 and 30915.—An 18-8 stainless steel, tough and stringy.

Nos. 51210 to 51710.—Stainless steels for various purposes.

TABLE 10.—ANALYSIS AND PROPERTIES OF STEELS USED BY FORD INDUSTRIES

Type of Steel	Steel Analysis, Percentage							Used for
	Carbon	Manganese	Chromium	Other Alloys	Silicon	Phosphorus	Sulphur	
AX	0.18 to 0.22	0.50 to 0.65	0.75 to 0.90		0.10 to 0.20	0.03 max	0.04 max	Spindles and bolts
AA	0.26 to 0.30	0.65 to 0.80	0.80 to 1.00		0.10 to 0.20	0.03 max	0.04 max	Graded by carbon content—used for general oil-hardening purposes
AAA	0.30 to 0.35	0.65 to 0.80	0.90 to 1.10		0.10 to 0.20	0.03 max	0.04 max	Graded by carbon content—used for general oil-hardening purposes
AAAH	0.35 to 0.38	0.65 to 0.80	0.90 to 1.10		0.10 to 0.20	0.03 max	0.04 max	Graded by carbon content—used for general oil-hardening purposes
AAAAL	0.38 to 0.42	0.65 to 0.80	0.90 to 1.10		0.10 to 0.20	0.03 max	0.04 max	Graded by carbon content—used for general oil-hardening purposes
AAAA	0.42 to 0.47	0.70 to 0.90	0.85 to 1.10		0.10 to 0.20	0.03 max	0.04 max	Graded by carbon content—used for general oil-hardening purposes
AAAAA	0.48 to 0.52	0.70 to 0.90	0.85 to 1.10		0.10 to 0.20	0.03 max	0.04 max	Graded by carbon content—used for general oil-hardening purposes
AA select	0.28 to 0.32	0.65 to 0.80	0.80 to 1.00		0.10 to 0.20	0.03 max	0.04 max	
AAA select	0.32 to 0.35	0.65 to 0.80	0.90 to 1.10		0.10 to 0.20	0.03 max	0.04 max	
Armature steel	0.05 max	0.30 max			0.12 to 0.28	0.03 max	0.04 max	Starter armature laminations

B	0.95 to 1.05	0.20 to 0.30	0.40 to 0.50	....	0.20 to 0.30	0.03 max	0.04 max	Ball bearing steel
BB	0.95 to 1.05	0.20 to 0.30	0.90 to 1.10	....	0.20 to 0.30	0.03 max	0.04 max	Ball bearing steel
BBB	0.95 to 1.05	0.30 to 0.40	1.25 to 1.50	....	0.20 to 0.30	0.03 max	0.04 max	Ball bearing steel
Bessemer No. 1	0.09 to 0.13	0.70 to 0.90	....	....	....	0.09 to 0.13	0.08 to 0.15	Screw machine work
C (key stock) (S.A.E. 1035)	0.30 to 0.40	0.50 to 0.80	....	....	0.10 to 0.20	0.05 max	0.05 max	
C (pure iron)	0.03 max	0.12 max	....	Copper optional	....	0.01 max	0.04 max	
Chrome nonshrink	1.45 to 1.60	0.25 to 0.35	11.00 to 12.00	V, 0.20 to 0.25; Mo, 0.70 to 0.90	0.20 to 0.40	0.03 max	0.04 max	Tools
CC	0.44 to 0.50	0.40 to 0.55	0.70 to 0.90	Tungsten 1.00 to 1.20	0.15 to 0.25	....	....	Cold chisels and punches
D	0.45 to 0.52	0.80 to 0.95	1.00 to 1.20	....	0.10 to 0.20	0.03 max	0.04 max	Spring leaves
DD	0.48 to 0.52	0.80 to 0.95	1.00 to 1.20	....	0.10 to 0.20	0.03 max	0.04 max	Spring leaves
Die block (Ajax)	0.60 to 0.75	0.30 to 0.40	3.25 to 3.75	....	0.10 to 0.20	0.03 max	0.04 max	
Die block (hammer)	0.47 to 0.55	0.50 to 0.60	0.60 to 0.75	Nickel, 1.50 to 1.75	0.10 to 0.20	0.03 max	0.04 max	
E	0.27 to 0.35	0.70 to 0.90	....	....	0.07 to 0.15	0.04 max	0.05 max	For general use where water quenching is used
EE	0.35 to 0.40	0.70 to 0.90	....	....	0.07 to 0.15	0.03 max	0.05 max	For general use where water quenching is used
EEE	0.40 to 0.45	0.70 to 0.90	....	....	0.07 to 0.15	0.03 max	0.05 max	For general use where water quenching is used
Electrical steel	0.05 max	0.30 max	....	....	0.90 to 1.20	0.03 max	0.03 max	Generator armature laminations
F	0.08 to 0.15	0.80 to 0.99	....	....	0.10 to 0.20	0.04 max	0.08 to 0.15	Free-cutting open-hearth steel
FF	0.15 to 0.20	0.80 to 0.99	....	....	0.10 to 0.20	0.04 max	0.10 to 0.15	Free-cutting open-hearth steel
FFF	0.34 to 0.40	0.80 to 0.99	....	....	0.10 to 0.20	0.04 max	0.10 to 0.15	Free-cutting open-hearth steel
Ford for high-speed steel (taps and drills)	0.65 to 0.73	0.25 to 0.35	3.75 to 4.25	V, 1.00 to 1.25; W, 17.0 to 18.0	0.20 to 0.30	0.03 max	0.04 max	Taps and drills

TABLE 10.—ANALYSIS AND PROPERTIES OF STEELS USED BY FORD INDUSTRIES—*Continued*

Type of Steel	Steel Analysis, Percentage							Used for
	Carbon	Manganese	Chromium	Other Alloys	Silicon	Phosphorus	Sulphur	
Ford for hot-work steel	0.18 to 0.23	0.40 to 0.60	1.40 to 1.60	Molybdenum, 0.45 to 0.55	0.15 to 0.25	0.04 max	0.04 max	Used for general tools
Ford special high-speed	0.78 to 0.84	0.25 to 0.35	4.00 to 4.50	V, 2.00 to 2.25; W, 18.0 to 19.0	0.20 to 0.50	0.03 max	0.04 max	Taps and drills
G	0.08 to 0.15	0.30 to 0.45			0.07 to 0.15	0.03 max	0.05 max	Used for general purposes
GG	0.15 to 0.20	0.30 to 0.45			0.07 to 0.15	0.04 max	0.05 max	Used for general purposes
Key stock (S.A.E. 2330)	0.25 to 0.35	0.50 to 0.80		Nickel 3.25 to 3.75		0.04 max	0.045 max	
L	0.23 to 0.30	0.35 to 0.50				0.04 max	0.05 max	High-tensile sheet steel
Low carbon, open hearth	0.05 to 0.15	0.30 to 0.50				0.04 max	0.05 max	Used for general press work
Machine steel	0.08 to 0.20	0.35 to 0.50			0.10 to 0.20	0.04 max	0.05 max	General machine repair
N	0.12 to 0.16	0.35 to 0.45	0.30 to 0.40		0.10 to 0.20	0.03 max	0.04 max	High-fatigue properties, piston pins
R	0.70 to 0.80	0.20 to 0.35	0.10 max	Nickel, none	0.15 to 0.25	0.025 max	0.03 max	General tool steels
RR	0.95 to 1.05	0.20 to 0.35	0.10 max	Nickel, none	0.15 to 0.25	0.025 max	0.03 max	General tool steels
RRR	1.20 to 1.30	0.20 to 0.35			0.15 to 0.25	0.025 max	0.03 max	General tool steels
Rustless steel 18–8	0.05 to 0.10	0.30 to 0.45	16.0 to 18.0	Nickel, 7.0 to 9.0	0.15 to 0.30	0.04 max	0.05 max	Pump shafts
Rustless 18	0.05 to 0.10	0.30 to 0.45	16.0 to 18.0		0.50 max	0.04 max	0.05 max	Hardware
Rustless type II	0.20 to 0.30	0.25 to 0.40	12.0 to 14.0		0.70 to 1.00	0.04 max	0.05 max	
S	0.60 to 0.70	0.70 to 0.85			0.15 to 0.20	0.03 max	0.04 max	Carbon spring steel for coil springs, minor springs, and bumpers

SS	0.70 to 0.85	0 70 to 0.85			0.10 to 0.20	0.03 max	0.04 max	Carbon spring steel for coil springs, minor springs, and bumpers
Tap steel (under 1-inch diameter)	1.20 to 1.30	0.25 to 0.40	0.35 to 0.45	V, 0.15 to 0.25; W, 1.25 to 1.50	0.30 to 0.45	0.025 max	0.025 max	
Welding wire	0.10 max	0.20 max				0.02 max	0.03 max	For welding electrodes
Insert die steel	0.55 to 0.60	0.45 to 0.60	0.70 to 0.80	Mo, 0.75 to 0.80; Ni, 2.25 to 2.45		0.03 max	0.04 max	Inserts in large die blocks
Vanadium tool steel	0.95 to 1.05	0.20 to 0.35	0.10 max	V, 0.40 to 0.50; Ni, none	0.15 to 0.25	0.025 max	0.03 max	
S.A.E. No. 4620	0.18 to 0.22	0.30 to 0.60	0.25 max	Mo, 0.20 to 0.30; Ni, 1.65 to 2.00	0.15 to 0.30	0.04 max	0.05 max	
Deep-drawing steel	0.05 to 0.08	0.28 to 0.38	0.04 max	Copper, 0.10 max		0.03 max	0.04 max	
"FFH"	0.20 to 0.25	0.80 to 0.99			0.10 to 0.20	0.04 max	0.10 to 0.15	

TABLE 10a.—FORD STANDARD IDENTIFICATION SYMBOLS FOR HIGH-SPEED STEEL CUTTING TOOLS

Cutting tools made or purchased by the Ford Motor Company are designated by the following symbols: All cutting steels in which tungsten is the major alloying element will be designated by the letter "T."

All cutting steels in which molybdenum is the major alloying element, even though tungsten is present, will be designated by the letter "M."

Tungsten High-Speed Steel, T				Analysis Symbol	Molybdenum High-Speed Steel, M				Analysis Symbol
18 % W.	4 % Cr.	1 % V		T-1	8 % Mo.	4 % Cr.	1 % V	1½ % W.	M-1
18 % W.	4 % Cr.	2 % V		T-2	5 % Mo.	4 % Cr.	1½ % V	6 % W.	M-2
18 % W.	4 % Cr.	3¼ % V		T-3	8 % Mo.	4 % Cr.	2 % V		M-10
18 % W.	4 % Cr.	1 % V	4 % Co.	T-4	8 % Mo.	4 % Cr.	1 % V	2½ % Co. Boron Added	M-20
18 % W.	4 % Cr.	2 % V	8 % Co.	T-5	8 % Mo.	4 % Cr.	1 % V	1½ % W. 4 % Co.	M-30
22 % W.	5 % Cr.	1½ % V	12 % Co.	T-6	8 % Mo.	4 % Cr.	1½ % V	8 % Co. Boron added	M-40
14 % W.	4 % Cr.	2 % V		T-7					
14 % W.	4 % Cr.	2 % V	5 % Co.	T-8					

Tough Steels for Truck Service

The Autocar Company uses the following nickel-alloy steels in their trucks, in the parts shown:

TABLE 11.—TRUCK STEELS

	Part	Steel Used	Treatment
Engine	Connecting rods	S.A.E. 2340	Heat-treated
	Connecting rod bolts	S.A.E. 3135	Heat-treated
	Inlet valve	S.A.E. 3140	Heat-treated
	Cylinder head studs, crankcase (main-bearing) studs	S.A.E. 2330	Heat-treated
Transmission	Transmission gears	S.A.E. 4620-1; 4820 and 3312	Case hardened
	Transmission main-shaft	S.A.E. 4340	Heat-treated
	Clutch collar	S.A.E. 4620-1	Case hardened
	Clutch hub	S.A.E. 4340	Heat-treated
	Transmission shifter rods	S.A.E. 3120	Heat-treated
Rear Axle	Rear axle driving axle shaft	S.A.E. 4340	Heat-treated
	Rear axle ring gear	S.A.E. 2520	Case hardened
	Rear axle bevel gears and jackshaft	S.A.E. 3312	Case hardened
	Rear axle differential gears	S.A.E. 2515	Case hardened
	Rear axle differential bolts	S.A.E. 2330	Heat-treated
	Rear axle hub studs	S.A.E. 2330	Heat-treated
	Rear axle wheel studs	S.A.E. 3135	Heat-treated
Front Axle	Front axle centers	S.A.E. 3130	Heat-treated
	Front axle spindles	S.A.E. 3130	Heat-treated
	Front axle steering arm	S.A.E. 3130	Heat-treated
	Steering ball bolt	S.A.E. 2515	Case hardened
Springing	Spring clips	S.A.E. 3120	Heat-treated
	Spring tube and bolt	S.A.E. 3115	Case hardened
	Spring cross shaft	S.A.E. 3140	Heat-treated
	Frame bracket bolts	S.A.E. 2330	Heat-treated

MACHINE-TOOL STEELS

Steels used in turret lathe and similar construction by the Warner and Swasey Company:

	S.A.E.	Type
Gears	No. 3150	Low Cr-Ni
Pinions, highly stressed	No. 3250	Med. Cr-Ni
Pinion shafts, highly stressed	No. 3250	Med. Cr-Ni
Heavy-duty clutches	No. 2512	5 per cent nickel
Highly stressed studs, bolts, screws	No. 3135	Low Cr-Ni
Sleeves and spline shafts	No. 2315	3½ per cent nickel
Lock bolts and bushings	No. 2315	3½ per cent nickel
Intricate parts requiring machining in heat-treated condition	No. 4140	Cr-Mo
Rolls, ball bearings	No. 52100	High Cr-C
Roller bearings	No. 4615	Cr-Mo-Ni

COLOR CODE FOR MARKING STEEL BARS

Simplified Practice Recommendation R166–37 was issued on April 1, 1937, by the Bureau of Standards, United States Department of Commerce, concerning a color code for marking steel bars. The work of preparing the recommendation was undertaken initially at the request of the National Committee on Iron and Steel of the National Association of Purchasing Agents. A recommendation was referred to all interests for consideration in August, 1935, and again resubmitted to industry in September, 1936. Since that time producers, users, and others concerned have accepted the code.

The color markings provided in the code may be applied by painting the end or ends of bars having a diameter of 1 inch or larger. For bars less than 1 inch in diameter, in bundles that are to be marked with one or two colors, the colors may be applied either by painting across the end or ends of the bundle, or marked on tags attached to the bundles. Where two colors are provided, the colors are applied side by side.

TABLE 12.—CARBON STEELS

S.A.E.	CODE COLOR
No. 1010	White
No. 1015	White
No. X1015	White
No. 1020	Brown
No. X1020	Brown
No. 1025	Red
No. X1025	Red
No. 1030	Blue
No. 1035	Blue
No. 1040	Green
No. X1040	Green
No. 1045	Orange
No. X1045	Orange
No. 1050	Bronze
No. 1095	Aluminum

TABLE 13.—FREE-CUTTING STEELS

S.A.E.	CODE COLOR
No. 1112	Yellow
No. X1112	Yellow
No. 1120	Yellow and brown
No. X1314	Yellow and blue
No. X1315	Yellow and red
No. X1335	Yellow and black
No. X1340	Yellow and black

The code gives color data for:

1. Only the steels in greatest demand. The revised code provides for 89 steels, whereas the current S.A.E. list covers over 140 chemical specifications.

2. Solid colors are reserved for carbon steels.
3. Striping is eliminated.
4. So far as possible, one color in combination with other colors is used for each series. For example, Table 13 shows that the key color for free-cutting steels is yellow, and that additional colors are added, such as brown, blue, red and black, to differentiate between different grades of free-cutting steels.

TABLE 14.—MANGANESE STEELS

S.A.E.	CODE COLOR
No. T1330	Orange and green
No. T1335	Orange and green
No. T1340	Orange and green
No. T1345	Orange and red
No. T1350	Orange and red

TABLE 15.—NICKEL STEELS

S.A.E.	CODE COLOR
No. 2015	Red and brown
No. 2115	Red and bronze
No. 2315	Red and blue
No. 2320	Red and blue
No. 2330	Red and white
No. 2335	Red and white
No. 2340	Red and green
No. 2345	Red and green
No. 2350	Red and aluminum
No. 2515	Red and black

TABLE 16.—NICKEL-CHROMIUM STEELS

S.A.E.	CODE COLOR
No. 3115	Blue and black
No. 3120	Blue and black
No. 3125	Pink
No. 3130	Blue and green
No. 3135	Blue and green
No. 3140	Blue and white
No. X3140	Blue and white
No. 3145	Blue and white
No. 3150	Blue and brown
No. 3215	Blue and purple
No. 3220	Blue and purple
No. 3230	Blue and purple
No. 3240	Blue and aluminum
No. 3245	Blue and aluminum
No. 3250	Blue and bronze
No. 3312	Orange and black
No. 3325	Orange and black
No. 3335	Blue and orange
No. 3340	Blue and orange
No. 3415	Blue and pink
No. 3435	Orange and aluminum
No. 3450	Black and bronze

TABLE 17.—MOLYBDENUM STEELS

S.A.E.	CODE COLOR
No. 4130	Green and white
No. X4130	Green and bronze
No. 4135	Green and yellow
No. 4140	Green and brown
No. 4150	Green and brown
No. 4345	Green and aluminum
No. 4350	Green and aluminum
No. 4615	Green and black
No. 4620	Green and black
No. 4640	Green and pink
No. 4815	Green and purple
No. 4820	Green and purple

TABLE 18.—CHROMIUM STEELS

S.A.E.	CODE COLOR
No. 5120	Black
No. 5140	Black and white
No. 5150	Black and white
No. 52100	Black and brown

TABLE 19.—CHROMIUM-VANADIUM STEELS

S.A.E.	CODE COLOR
No. 6115	White and brown
No. 6120	White and brown
No. 6125	White and aluminum
No. 6130	White and yellow
No. 6135	White and yellow
No. 6140	White and bronze
No. 6145	White and orange
No. 6150	White and orange
No. 6195	White and purple

TABLE 20.—TUNGSTEN STEELS

S.A.E.	CODE COLOR
No. 71360	Brown and orange
No. 71660	Brown and bronze
No. 7260	Brown and aluminum

TABLE 21.—SILICON-MANGANESE STEELS

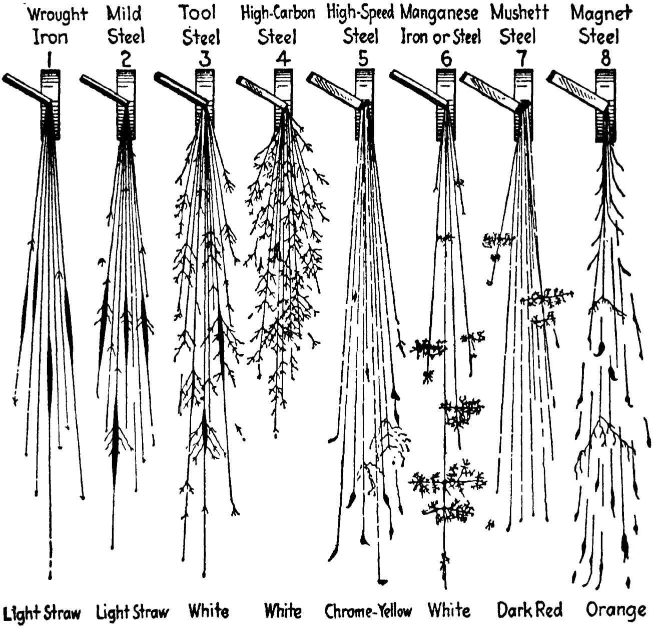
S.A.E.	CODE COLOR
No. 9255	Bronze and aluminum
No. 9260	Bronze and aluminum

THE SPARK METHOD OF DETERMINING GRADES OF IRON AND STEEL

The method of determining the kind of ferrous material illustrated herewith was devised by John F. Keller, instructor of forging at Purdue University, Lafayette, Ind., and has proved very successful as a practical shop test. See the illustration on page 1054. The material should touch the wheel lightly, and the spark should be carefully watched.

TESTS OF HARDNESS

The hardness of metals, particularly of steels which are heat-treated, is now tested with either the Shore Scleroscope, or by the Brinell or Rockwell method, as described on page 1017.



Spark Test for Grades of Steel.

The Brinell Test

The Brinell method of testing consists of forcing a hardened steel ball of given dimension into the metal to be tested under a given pressure. The diameter of the impression made is read with a graduated microscope and the hardness found by consulting a table like that shown on page 1058. In this the ball is 10 millimeters in diameter. If, with a pressure of 3,000 kilograms, as indicated by the testing machine, the diameter of the depression is 3 millimeters, the hardness number is 415 with a standard ball or 418 with a tungsten-carbon ball. Comparative test values are given for Rockwell, monotron and other methods of testing.

Cloudburst Hardness Testing

In this test, devised by Edward G. Herbert of England, the work is subjected to a shower of hard steel balls falling from a given height. Some of the smaller machines use 3-millimeter or ⅛-inch balls falling from a height of 2 to 4 meters at the rate of about 750,000 per minute. These balls normally make no visible depression, but they so affect the surface that hard and soft spots are clearly shown. Balls of 5 millimeters in diameter are also used.

In testing manufactured parts by this process[1] a block of the desired hardness is placed in the machine and the distance the balls fall adjusted so that they just fail to mark the surface. Then work pieces which are not marked are at least as hard as the standard. Soft spots will be marked by the balls.[1]

File Hardness Tests[2]

Files are still used to test hardness. Standard files for this purpose can be obtained from reputable file makers. One maker recommends a 10-inch mill, bastard file. Others suggest 6- or 8-inch pillar or three-square files. One maker states that special files which will not cut straight carbon steel immediately after quenching to Rockwell C64–66 will cut it after tempering to 375°F. though the Rockwell hardness remains the same.

Monotron Hardness Test[3]

This testing machine registers on a dial the load required to produce a definite penetration. Two dials are used, one measuring pressure, and the other, the depth of penetration. The depth indicator shows the extent of elastic recovery of the specimen and of permanent deformation. The diamond ball used is ¾ millimeter in diameter and penetrates to a depth of $\frac{9}{5000}$ inches. A scale known as M-1 reads directly in Brinell numbers.

Vickers Diamond Pyramid Hardness Test[4]

This is similar to the Brinell method but uses a diamond, cut rod polished to the shape of a square-based pyramid. This gives a square impression which is easily read across the corners. The impression appears as a dark square on a light ground. The hardness numbers compare with Brinell up to about 300. At higher values the Brinell falls progressively lower and is not reliable above about 600 Brinell. The irregularity is caused by the flattening of the balls under heavy loads.

Magnaflux Method of Detecting Cracks

As cracks of all kinds, whether in the original bar of steel, or due to heat or fatigue stresses afterwards, precede failure, it is important to detect them before failure occurs. The Magnaflux method, by which the piece is magnetized and forms north and south magnetic poles each side of the crack, has become standard practice on all airplane engine parts and in other places where failure would be disastrous.

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[1] R. C. Brumfield.
[2] H. T. Morton.
[3] O. W. Boston.
[4] S. L. Goodole and B. B. Rosenbaum.

Two methods are used, known as the "wet" and "dry" methods. In both, the parts to be inspected are magnetized by suitable means. In the wet method the magnetized part is then dipped in a tank in which a very fine powder of magnetic oxide is suspended in a liquid resembling kerosene. If there is a crack, the powder gathers at that point, even where the crack is so small as to be invisible with 100 times magnification.

In the dry method the magnetic powder is sifted over the part to be tested and forms along the line of any crack that may exist. The parts can be magnetized in any convenient way. A common method is to put a magnetic coil over a part at each end of the place to be tested.

Comparison of Hardness Numerals

Table 22 is a very complete comparison of different methods of testing materials. It was prepared by the Chapman Valve Manufacturing Company.

SHOP RECIPES

U. S. Armory Browning Solution

First, make "tincture of steel," by putting 3 pounds of carbonate of iron in a stone jar and pouring over this 3 quarts of muriatic acid. Let this stand, stirring it occasionally, until the acid "cuts" or takes up all of the iron that it will. After the muriatic acid becomes saturated with the carbonate of iron, pour it into a glass demijohn, being careful that none of the remaining sediment goes with it. To this add 9 quarts of grain alcohol, completing the tincture of steel.

To make the Browning solution proper, take 6 ounces of the tincture of steel, 6 ounces of sweet spirits of niter, 1 ounce of nitric acid, ½ ounce of sulphate of copper, 1 ounce of corrosive sublimate, and 2 quarts of soft water, using a glass stopped bottle to prevent evaporation.

This should stand for 24 hours, if possible, although it can be used immediately, but does not give so good results. The solution is applied with a sponge.

U. S. Armory Etching Acid

There are sometimes pieces that are riveted in place after being browned. As the riveting must be smoothed down, thereby removing the browning, a special etching acid is used for coloring the polished portions to match the browning previously put on. The etching acid is comprised of 1 ounce of tincture of steel, previously mentioned, 2 ounces of corrosive sublimate, and 1 ounce of nitric acid. Some of the etching acid is put in a shallow glass dish, and the parts to be colored are dipped into it. In order to check the working of this acid, the parts are immediately dipped in hot water, and then in a dish of ammonia at full strength, and finally covered with oil.

Table 22.—Hardness Strength of Steel

The following table (prepared by Sir Robert Hadfield of the Research Laboratory, Hadfields, Ltd., Sheffield, England) represents the average of a large number of tests on all types of steel, and is intended as an approximate guide. Individual results vary considerably from the average. It also gives a comparison of Brinell ball and Scleroscope hardness numbers with their relation to the compression strength, also yield point and tenacity, of steel.

Zones of Hardness F to A	Approx. Scleroscope Hardness Number	Brinell Ball Hardness Number	Tensile Strength				Compression on Specimens .564″ Diam. and .70″ in Height		
			Yield Point		Maximum Stress		Elastic Limit and 25% Compression		Compression, Per Cent. (100 Tons per Sq. In.) (160 Kilograms) per Sq. M/M
			Tons per Sq. In.	Kilograms per Sq. M/M	Tons per Sq. In.	Kilograms per Sq. M/M	Tons per Sq. In.	Kilograms per Sq. M/M	
F		150	20	31	36	57	17	27	49.0
		175	26	41	41	65	19	30	40.0
	34	200	32	50	46	72	21	32	35.0
E	38	225	38	60	51	80	23	36	31.0
	42	250	44	69	56	88	26	41	27.9
	46	275	50	79	61	96	30	47	23.0
	50	300	56	88	66	104	34	54	19.0
D	54	325	61	96	71	112	38	60	15.2
	57	350	67	105	76	120	43	68	11.3
	61	375	73	115	81	128	49	77	8.0
	64	400	79	124	86	135	55	87	5.6
C	68	425	84	132	91	143	61	96	3.8
	71	450	90	142	96	151	67	105	2.4
	75	475	96	151	101	159	74	116	1.3
	78	500	102	161	106	167	81	127	0.6
B	80	525	107	169	111	175	87	137	0.23
	84	550	113	178	116	183	94	148	0.21
	86	575			121	190	101	159	0.20
	89	600			126	198	108	170	0.18
A	92	625*	Not determined				115	181	0.16
	95	650			131	206	122	192	0.14
	99	675			136	214	129	203	0.13
	101	700			141	222	136	214	0.12

* Glass scratching hardness commences here.

Hardening Cast Iron

According to a British authority cast iron can be hardened by heating to 1550°F., and by heating to 1650°F and quenching in oil. This increases hardness from 259 to 474 Brinell but reduces the breaking strength nearly one-half. Reheating to 570°F is said practically to restore the strength and only reduces the Brinell to 425. Heating the iron to 700°F. makes the iron stronger than

TABLE 23.—CONVERSION TABLE OF HARDNESS NUMERALS—CHAPMAN VALE MANUFACTURING CO.

Vickers or Firth	Brinell			Rockwell Standard					Rockwell Superficial				Durometer	Monotron		Drop Hardness, Mm. Kgs.	Hebert Pendulum		Scleroscope	Duroscope	Moh
	Diameter, Millimeters	Standard Ball	Tungsten Carbide Ball	150 Kilograms C	100 Kilograms D	60 Kilograms A	1/16-Inch Ball B	1/8-Inch Ball E	15-N	30-N	45-N	30-T		Constant Diameter	Diameter, Brinell		Time *S*	Time *D*			
1224	2.20	780	872	..	..	....	...	...	....	....	....	..	28	130	1200	....	90	64	106	..	
1116	2.25	745	840	..	..	....	...	...	....	....	....	..	31	122	1130	....	85	59	102	..	8.5
1022	2.30	712	812	..	..	....	...	...	....	....	....	..	32	111	1030	....	80	56	98	..	
941	2.35	682	794	65	73	84.5	...	...	92.5	82	72	..	34	103	956	....	76	52	94	....	
868	2.40	653	760	64	72	83	...	...	92	81	71	..	37	96	894	....	72	49	91	54	
804	2.45	627	724	62	71	82.5	...	...	91	79	69	..	40	91	850	....	67	47	87	53	8.0
746	2.50	601	682	60	70	81.5	...	...	90	77.5	66.5	..	43	86	804	....	63	45	84	52	
694	2.55	578	646	58	68	80.5	...	...	89	76	64.5	..	45	82	767	1400	60	42	81	51	
650	2.60	555	614	56	67	79.5	...	...	88	74	62	..	46	78	727	1300	56	40	78	50	
606	2.65	534	578	54	65	78.5	...	...	87	72.5	60	..	48	74	690	1225	53	38	76	49	
587	2.70	514	555	52	64	77.5	...	...	86	70.5	57.5	..	49	71	660	1160	51	37	73	49	
551	2.75	495	525	50	63	76.5	...	...	85	69	55	..	50	68	630	1095	48	36	71	48	
534	2.80	477	514	49	62	76	...	...	84.5	68	54	....	51	66	610	1050	47	35	68	48	
502	2.85	461	477	48	61	75.5	...	...	84	67	53	..	52	63	586	1005	44	34	66	47	
474	2.90	444	460	46	60	74.5	...	...	83	65.5	51	..	53	61	566	950	41	33	64	46	7.0
460	2.95	429	432	45	59	74	...	...	82.5	64.5	49.5	..	55	59	548	910	39	32	62	46	
435	3.00	415	418	43	58	73	...	...	81.5	62.5	47.5	..	56	57	530	880	37	30	61	45	
423	3.05	401	401	42	57	72.5	...	...	81	62	46.5	..	58	55	510	840	35	29	59	45	
401	3.10	388	388	41	56	72	...	...	80.5	61	45	..	59	53	490	810	34	28	57	44	
390	3.15	375	375	40	56	71.5	...	...	80	60	44	..	60	51	471	780	33	27	56	44	6.5
380	3.20	363	364	39	55	71	...	...	79.5	59	43	..	62	50	462	750	32	26	54	43	
361	3.25	352	352	38	54	70.5	...	...	79	58	42	..	63	48	453	725	30	26	53	43	
344	3.30	341	341	36	53	69.5	...	...	78	56.5	39.5	..	64	47	433	700	29	25	51	42	
334	3.35	331	330	35	52	69	...	...	77.5	56	38.5	..	65	45	414	675	28	24	50	42	
320	3.40	321	321	33	50	67.5	...	...	76.5	54	36	..	66	44	408	650	27	24	49	41	
311	3.45	311	311	32	50	67	...	...	76	53	35	..	68	42	390	630	26	23	47	41	
303	3.50	302	302	31	49	66.5	...	...	75.5	52	34	..	69	41	380	610	24	23	46	40	6.0
292	3.55	293	...	30	48	66	...	...	75	51.5	33	..	70	40	370	590	24	22	45	40	
285	3.60	285	...	29	47	65.5	...	...	74.5	50.5	31.5	..	71	39	360	570	23	22	44	40	

278	3.65	277	...	28	47	65	...	...	74	49.5	30.5	..	72	38	350	550	23	21	43	39	
270	3.70	269	...	27	46	64.5	...	...	73.5	48.5	29.5	..	73	37	340	535	22	21	42	39	
261	3.75	262	...	26	45	64	...	...	73	48	28.5	..	75	36	331	520	22	20	41	38	
255	3.80	255	...	25	45	63.5	...	...	72.5	47	27	..	76	35	322	505	21	20	40	38	
249	3.85	248	...	24	44	63	...	...	72	46.5	26	..	77	34	313	490	21	19	39	37	5.5
240	3.90	241	...	23	43	62.5	102	...	71.5	46	25	85	78	33	304	475	20	19	38	37	
235	3.95	235	...	21	42	61.5	101	...	70.5	44	23	84	79	32	295	460	20	19	37	37	
228	4.00	229	...	20	41	61	100	...	70	43	22	83	81	31	286	450	19	18	36	36	
222	4.05	223	...	19	40	....	99	...	....	....	....	82	82	30	277	440	19	18	35	36	
217	4.10	217	...	17	39	....	98	110	....	....	....	82	83	29	268	430	19	18	34	36	
213	4.15	212	...	15	38	....	97	110	....	....	....	81	84	29	268	415	18	17	34	35	
208	4.20	207	...	14	37	....	95	110	....	....	....	81	86	28	259	405	18	17	33	35	
201	4.25	201	...	13	37	....	94	109	....	....	....	80	87	28	259	395	18	17	32	35	
197	4.30	197	...	12	36	....	93	109	....	....	....	79	88	27	250	385	17	16	31	34	
192	4.35	192	...	11	35	....	92	108	....	....	....	78	89	26	....	375	17	16	30	34	5.0
186	4.40	187	...	9	34	....	91	108	....	....	....	78	90	26	....	365	17	16	30	34	
183	4.45	183	...	8	34	....	90	108	....	....	....	77	92	25	....	360	17	16	29	33	
178	4.50	179	...	7	33	....	90	107	....	....	....	77	93	25	....	350	17	16	29	33	
174	4.55	174	...	6	33	....	89	107	....	....	....	76	94	24	....	340	16	15	28	33	
171	4.60	170	...	4	32	....	88	106	....	....	....	76	95	23	....	335	16	15	28	32	
166	4.65	167	...	3	32	....	87	106	....	....	....	75	96	23	....	330	16	15	27	32	
162	4.70	163	...	2	31	....	86	105	....	....	....	74	97	22	....	320	16	15	27	32	
159	4.75	159	...	1	31	....	85	105	....	....	....	73	99	22	....	315	16	15	26	31	
155	4.80	156	...	0	30	....	84	104	....	....	....	73	100	21	....	310	16	15	26	31	
152	4.85	152	...	..	..	....	83	104	....	....	....	72	102	21	....	300	16	15	25	31	
149	4.90	149	...	..	..	....	82	103	....	....	....	71	104	20	....	295	15	14	24	30	4.5
146	4.95	146	...	..	..	....	81	103	....	....	....	71	105	20	....	290	15	14	24	30	
143	5.00	143	...	..	..	....	80	102	....	....	....	70	106	19	....	285	15	14	24	30	
140	5.05	140	...	..	..	....	79	102	....	....	....	69	108	19	....	280	15	14	23	29	
138	5.10	137	...	..	..	....	78	101	....	....	....	68	109	19	....	275	15	14	23		
134	5.15	134	...	..	..	....	77	101	....	....	....	68	111	18	....	270	15	14	23		
131	5.20	131	...	..	..	....	76	100	....	....	....	67	113	18	....	265	14	13	22		
129	5.25	128	...	..	..	....	75	100	....	....	....	67	115	18	....	260	14	13	22		
127	5.30	126	...	..	..	....	74	99	....	....	....	66	116	17	....	255	14	13	22		
123	5.35	123	...	..	..	....	73	99	....	....	....	66	117	17	....	250	14	13	21		
121	5.40	121	...	..	..	....	72	98	....	....	....	65	119	17	....	245	14	13	21		
118	5.45	118	...	..	..	....	71	98	....	....	....	64	121	16	....	240	14	13	21		
116	5.50	116	...	..	..	....	70	97	....	....	....	63	122	16	....	235	..	..	20		
115	5.55	114	...	..	..	....	68	97	....	....	....	63	123	16	....	233	..	..	20		
113	5.60	111	...	..	..	....	67	96	....	....	....	62	124	15	....	230	..	..	20		
110	5.65	110	...	..	..	....	66	95	....	....	....	61	126	15	....	228	..	..	20		
109	5.70	109	...	..	..	....	65	95	....	....	....	60	127	15	....	225	..	..	19		
108	5.75	107	...	..	..	....	64	94	....	....	....	59	128	14	....	223	..	..	19		

originally but reduces the Brinell to 390. Heating still hotter, to 925, again reduces the strength and gives a Brinell of 342.

Some cast irons can be hardened by subjecting them to ammonia gas at 925 to 1025°F. for a long period, one test being for 80 hours. This gives a very hard surface. Cast iron is sometimes hardened by heating to bright red in cyanide and quenching. Gage points have been hardened in this way for temporary or infrequent use.

How to Niter-Blue Steel

Immerse the chemically clean components in a mixture of 10 parts of niter (saltpeter) to 1 part of black oxide of manganese (MnO_2), by weight, heated to 800 to 850°F. The mixture should be contained in a cast-iron pot, heated by any suitable fuel.

Best results are obtained when the components are contained in a wire basket. They are allowed to remain in the niter for from 5 to 10 minutes, the longer the time, the darker the blue.

Upon withdrawing the components, quench them in water at a temperature of from 125 to 150°F., and when dry, cover them with raw linseed oil and allow them to drain.

Springs are generally drawn back at from 450 to 600°F., depending upon the analysis of the steel. Higher carbon content requires higher temperature. Even the 600-degree tempering temperature is too low for the niter-bluing process and another method must be used. To get good results have the springs clean and then heat them on the surface of a layer of sand, contained in a pan, either in the furnace or by a fire applied underneath the pan, until the color desired has been obtained. The parts should be turned occasionally during the heating, and after the coloring has been completed, they should be spread out to cool.

Quenching or Cooling Steel

Cooling apparatus is divided into two classes—baths for hardening and the different appliances for annealing.

The baths for quenching are composed of a large variety of materials. Some of the more commonly used are as follows, being arranged according to their intensity on 0.85 per cent carbon steel: mercury; water with sulphuric acid added; nitrate of potassium; sal ammoniac; common salt; carbonate of lime; carbonate of magnesia; pure water; water containing soap, sugar, dextrine, or alcohol; sweet milk; various oils; beef suet; tallow; wax. These baths, however, do not act under all conditions with the same relative intensity, as their conductivity and viscosity vary greatly with the temperature.

With the exception of the oils and some of the greases, the quenching effect increases as the temperature of the bath lowers. Sperm and linseed oils, however, at all temperatures between 32 and 250°F., act about the same as distilled water at 160 degrees.

Arsenal "Hot-Dip" Process for Tinning

Use a metal composed of 80 parts of lead to 20 parts of tin by weight. The steel plate to be tinned is first pickled in a bath of 40 parts of water to one part of sulphuric acid by volume. After pickling, the metal is washed in clean water to remove all traces of the pickling acid. The work is then dipped in a flux which is made by dissolving zinc in hydrochloric acid until it is saturated. After dipping in the flux, the pieces are dipped in the melted metal (80 per cent lead, 20 per cent tin) until thoroughly coated and are then shaken off and thrown in a pile to cool.

A Method of Tinning Brass Parts

Brass parts are placed in layers in a screened basket with tin plates between each layer. They are then placed in a copper tank filled with water supplied with steam coil and brought to a boiling point. Sufficient amount of cream of tartar is added until the parts are properly plated. Four hours are required to properly tin these parts.

Small parts are placed in a cheesecloth bag in a solution of one pint of phosphoric acid (U.S.P. 50 per cent) to four gallons of water. Heat to a boiling point until parts begin to turn white, requiring about 2 hours. Remove and place in linseed oil. They are then rolled on straw boards to remove the surplus oil.

Etching Fluid

An etching fluid for etching steel by the use of rubber stamps is made as follows:

Nitric acid	75 parts
Nitrate of silver	2 parts
Water	23 parts

To use, a piece of blotting paper or thin asbestos is laid on a sheet of glass and saturated with the fluid which takes the place of the ink generally used with rubber stamps. The stamp is pressed on the saturated pad and then on the steel which is etched lightly with the desired design.

After using, the saturated paper should be destroyed as it tends to rust any ferrous material near it.

Rust Remover

For rust remover mix the following ingredients:

Petrolatum	3 ounces
P 907 oil	2 ounces
Tripoli	6 ounces

P 907 oil is made by the Vacuum Oil Company. A similar oil is made by the Texas Oil Company known as "Spindle oil B." Either can be used.

Steam the two oils together until very warm, and then add the Tripoli. Spread the mixture on the rusted part. Rub off with a cloth after a few moments and the rust should come off with it.

Marking on Steel

For marking steel a china-marking pencil may be used. This will mark just as readily and distinctly on almost any polished surface, such as steel, brass, or nickel. It makes a sharp line that is distinct; it does not injure the surface, and the mark does not come off too easily.

THE PICKLING OF IRON AND ITS ALLOYS[1]

Pickling consists in treating metals with dilute acid solutions to remove scale or rust. Scales on iron and its various alloys are usually iron oxides classifiable in three groups:

1. Hydrated ferric oxide (Fe_2O_3, H_2O)—ordinary brown rust and soluble in dilute pickling acid.
2. Anhydrous ferric oxide (Fe_2O_3)—similar to brown rust but formed in the absence of water. It is the commonly known "blue scale" and is somewhat soluble in pickling acids.
3. Magnetic oxide (Fe_3O_4)—the black scale formed in hot-working operations, and only slightly soluble in acids.

Scales which must be removed by pickling consist chiefly of the two last-mentioned oxides which are removed not so much by dissolving the scale itself as by the resultant mechanical action. A thin layer of metal only enters into the solution when the acid penetrates the scale, but the forming of hydrogen forces scale off mechanically, and it falls to the bottom of the tank.

Pickling acids have little or no effect on oil, grease, or lubricating compounds which must be removed before pickling. Proper cleaning of the material before pickling has a markedly beneficial effect on pickling results. At the same time as much as one-half of the acid otherwise required may be saved where proper cleaning for grease, etc., precedes pickling.

Acids

Sulphuric acid is most commonly used for pickling, owing chiefly to its low cost. Concentrations of the pickling solutions vary from 2 per cent to 15 per cent acid, the bath being heated in order to insure the maintenance of a fairly rapid rate of pickling. An unfortunate disadvantage of such hot baths is that the fumes are disagreeable, but in modern plants ventilation systems have eliminated much of the trouble.

Muriatic acid is used in strengths of 10 to 50 per cent commercial acid. While the pickling action of this acid is more rapid and lower temperature can be maintained in the baths, the use of muriatic acid is generally prohibited on account of its high cost as compared with sulphuric acid.

Acid Strength and Temperature

Acid strength and temperature should be considered together, for both factors affect the rate of pickling. Pickling may be speeded up by increasing the acid content up to about 20 per cent actual acid. Beyond this point an increase in acid slows down pickling. In actual practice the acid strength is between 2 and 15 per cent.

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[1] **Weaver Brothers, Clinton, Mich.**

Changes in temperature have a greater influence on rate of pickling than do variations in acid strength. An increase of 20°F. will double the rate of pickling. The temperature range for most pickling operations is between 140 and 180°F.

Acid content and temperature are largely dependent upon individual plant conditions and tank capacities. Acid strength of 5 per cent and temperatures between 140 and 180°F. are advisable in most cases, giving as they do a minimum of fumes and the best working conditions. Stronger solutions and higher temperatures will increase production, but the added tonnage will be attended by greatly increased volume of fumes, together with the danger of overpickling, pitting, and acid brittleness.

Use a good inhibitor.

Since no matter what the class of work may be, the conditions for good pickling hinge upon each other, they can be determined and fixed for control for the foreman with the aid of simple tools. All he needs is a thermometer, a burette, a clock, and a hydrometer, and he can pickle metals accurately and well.

COPPER ALLOYS

Strictly, a brass is a copper-zinc alloy containing one-third zinc and two-thirds copper; whereas a bronze is a copper-tin alloy containing approximately 10 per cent tin and 90 per cent copper. The old-style gun metal contained from 90 to 92 per cent copper and from 8 to 10 per cent tin. Lead is frequently added to both

Composition of Bronzes (Navy Department)

	Parts
White Metal:	
Tin	7.6
Copper	2.3
Zinc	83.3
Antimony	3.8
Lead	3.0
Hard Bronze for Piston Rings:	
Tin	22.0
Copper	78.0
Bearings—Wearing Surfaces, etc.:	
Copper	6
Tin	1
Zinc	½
Naval Brass:	
Copper	62.0
Tin	1.0
Zinc	37.0
Brazing Metal:	
Copper	85.0
Zinc	15.0
Antifriction Metal:	
Copper (best refined)	3.7
Banca tin	88.8
Regulus of antimony	7.5
Well fluxed with borax and rosin in mixing.	
Bearing Metal (Pennsylvania Railroad):	
Copper	77.0
Tin	8.0
Lead	15.0

Admiralty bronze, for condenser tubes; copper 70, zinc 29, tin 1.

Phosphor bronze: copper 85–90, zinc 3, tin 6–10, traces of iron, lead and phosphorus.

TABLE 24.—CLASSIFICATION OF COPPER-BASE ALLOYS

Alloys	General Composition, Per Cent				General Characteristics	General Uses
	Copper	Zinc	Lead	Tin		
Commercial bronze 95 per cent	95.0	5.0	...	....	Copper colored, pliable	Primer cups, bullet jackets, jewelry
Commercial bronze 90 per cent	90.0	10.0	...	....	Resists corrosion and atmospheric action	Automobile radiators, screens, radios
Red brass 85 per cent	85.0	15.0	...	....	Resists corrosion and atmospheric action	Tubing, hardware
Red brass 80 per cent	80.0	20.0	...	....	Resists sea water and atmospheric corrosion	
Brazing brass	75.0	25.0	...	....	....	Parts to be brazed or silver soldered
Spring brass	72.0	28.0	...	....	Withstands drastic treatment	Springs, rods, etc.
Cartridge brass, grade A comm.	70.0	30.0	...	....	. .. .	Seamless tubes, deep drawings
Eyelet brass, grade B comm.	68 0	32.0	...	...	. . . .	Eyelets, drawn shells
Drawing or spinning brass	66.67	33.33	...	...	....	Deep drawings
Commercial brass, grade C	65.0	35.0	...	....	Not good for weather exposure unless annealed	Fixtures, radiators, ornaments
Brass wire	63.0	37.0	...	..	....	Rivets, pins, screws, heading operations
Muntz metal	60.0	40.0	...	....	Worked hot, finished by cold working	Bolts, nuts, sheathing, wire
Leaded-low brass	78.5	20.0	1.5	....	Free cutting	Rivets, similar articles
Turning rod	62.0	35.0	3.0	....	Machines easily	Automatic machine work
Clock brass	61.5	37.0	1.5	....	Free milling	Meter and clock parts, gears
Admiralty metal	70.0	29.0	...	1 0	Resistant to sea water	Condenser tubes, ferrules
Tobin bronze or naval brass	60.0	39.25	...	0.75	Stronger than commercial brass rod. Resistant to sea water	Rods, bolts, nuts, piston rods, propeller shafts, plates
Everdur,* cast	94.4	....	...	....	Has corrosion-resisting properties of copper and physical properties of mild steel	Cold or hot rolled, forged
Everdur,† wrought	96.0	....	...	....		

* Patented 1925; contains 4.5 per cent of silicon and 1.0 per cent of manganese.

† Patented 1925; contains 3.0 per cent of silicon and 1.0 per cent of manganese.

NOTE FOR TABLE 24

These alloys are usually furnished in the following tempers and anneals:

TEMPERS	REDUCTION, B. &. S. GAGE
Quarter Hard	1
Half Hard	2
Hard	4
Extra Hard	6
Spring	8

ANNEALS

Light
Drawing
Soft Drawing

these classes of alloy to make them machine more easily, and both tin and zinc are commonly used in the same alloy, so that today we have a series of copper-tin-zinc alloys of almost infinite variety. In all cases in the useful alloys of this class, however, there is present more than 50 per cent copper.

In most of the modern alloys tin is depended upon to give strength and zinc to cheapen the mixture. Some of the old-style gun metals contained as much as 16 per cent tin and 84 per cent copper, but such metals were brittle and hard. The common yellow brass employed by plumbers in making ordinary valves and fittings may be considered as composed of approximately 16 pounds of copper, 8 pounds of zinc, and ½ pound of lead. It will be noticed that this consists of approximately one-third zinc and two-thirds copper, with a little lead added to improve the machining qualities. For the making of high-grade castings, ingots or new metal should be used in all cases. In making a brass the copper should be melted first and the zinc added, care being taken not to let the temperature rise too high, for if it does, the zinc will ignite and burn. The lead is added last and the metal thoroughly stirred.

Navy Department Specifications for Journal Bronze (Composition H)

The chemical properties shall be as follows:

Copper, Per Cent	Tin, Per Cent	Zinc, Per Cent	Iron (Maximum), Per Cent	Lead (Maximum), Per Cent	Normal
82–84	12.5–14.5	2.5–4.5	0.10	1.0	83–13½–3½

BRASS TERMINOLOGY

Admiralty Metal.—Contains 70 per cent of copper, 29 per cent of zinc, and 1 per cent of tin. Care must be taken not to confuse admiralty metal with admiralty gun metal or admiralty bronze, names frequently applied to a sand-cast alloy containing 88 per cent of copper, 10 per cent of tin, and 2 per cent of zinc. Admiralty metal is one of the best known alloys for condenser and heat-exchanger tubes.

Aluminum Bronze.—Has 1.25 to 11 per cent aluminum.

Brass Forging Rod.—Is an alloy containing 60 per cent of copper, 38 per cent of zinc, and 2 per cent of lead. It is extensively used in the manufacture of parts by hot-forging and hot-pressing operations.

Brass Rod.—Specifically designates a free-cutting alloy of 61.5 per cent of copper, 35.5 per cent of zinc, and 3 per cent of lead. It is extensively used in automatic screw machine work, where ease and speed of cutting are important factors.

Cartridge Brass.—Designates an alloy of about 70 per cent of copper and 30 per cent of zinc. The term implies an alloy low in impurities. Cartridge brass possesses a high degree of mechanical strength combined with good ductility.

High Brass.—Is a general term applied to alloys containing about 2 parts of copper to 1 part of zinc. The A.S.T.M. recognizes two grades. No. 1 grade is frequently known as spinning brass, eyelet brass, or drawing brass. No. 2 grade is generally known as "common high brass." It has less copper than No. 1.

Low Brass.—Contains 80 per cent of copper and 20 per cent of zinc. Another grade, known as "rich low brass" contains 85 per cent of copper and 15 per cent of zinc.

Manganese Bronze.—The 18.5 per cent manganese gives a white-colored alloy. Adding 1.25 per cent aluminum tends to prevent oxidation.

Muntz Metal.—Is an alloy of 60 per cent of copper and 40 per cent of zinc. It is used for condenser tube applications, and gives good service in the circulation of clean, fresh water. It is not recommended for use with salt water or polluted fresh water.

Naval Brass.—Is 60 per cent of copper, 39.25 per cent of zinc, and 0.75 per cent of tin.

Red Brass.—Has 85 or more per cent of copper. Tin gives it an orange color.

High-Silicon Bronzes

Duronze is a high-silicon bronze alloy of the Bridgeport Brass Company. It is made in four grades for different uses. It weighs less than copper and melts at a lower point. Both weight and melting point depend on the grade.

Machining practice for this is about the same as for steel. Tools should not be set much above the center, and no land is permissible. Tools recommended are shown. Speeds and feeds for drilling and turning are shown in the tables.

Drills with a short helix are best. Undercutting the edges to increase rake angle is suggested for long drills. Drills with narrow, polished margins are best. Drills should cut constantly to avoid glazing and work hardening of the metal. Use plenty of lubricant. Oil hole drills advisable in large or deep holes.

Taps should have back taper and narrow lands, with flutes of 10 to 15 degrees lip. Chamfer should cover two threads, and tapping speeds should be about 20 feet per minute with plenty of sulphurized oil. Tap drills larger than standard and oversize taps are recommended.

Thread chasers in dies should have 10 to 15 degrees lip or hook and a narrow land. Speed 15 to 20 feet per minute.

Reamers should have narrow lands and well polished flutes.

Milling cutters with coarse teeth are recommended to permit chip removal. A cutting rake of 10 to 15 degrees, with 10 degrees back rake, is suggested. Use plenty of good lubricant. Form cutters should have top and side rake and no lands. Ample chip clearance is essential. Speeds of 45 to 55 feet per minute and feeds of 0.003 to 0.008 inch are suggested. Cuts deeper than ¼ inch may give trouble.

Uses of S.A.E. Brass and Bronze Alloys

DESCRIPTIONS OF BRASS AND BRONZE ALLOYS

A survey of motor vehicle and parts manufacturers in 1932–33 indicated that S.A.E. brass and bronze specifications are used in parts and types of service such as those listed below:

No. 40. **Red Brass.**—Water-pump impellers, fittings for gasoline and oil lines, small bushings, small miscellaneous castings.

No. 41. **Yellow Brass.**—Radiator parts, fittings for water-cooling systems, battery terminals, miscellaneous castings.

No. 42. **White Nickel Brass.**—Control brackets, levers to match nickel-silver trimmings and fittings on motorboats.

No. 43. **Manganese Bronze.**—Gear-shifter forks, counters, spiders, brackets and similar fittings, parts for starting motors, landing-gear and tail-skid castings for airplanes.

No. 44. **Brass to Be Brazed.**—Fittings for water pipes which are brazed.

No. 45. **Brazing Solder.**—For brazing.

No. 62. **Hard Bronze.**—Gears, bearings, bushings for severe service, valve guides, valve-tappet guides, camshaft bearings, fuel pump, timer and distributor parts, connecting-rod bushings, piston pins, rocker lever, steering-sector and hinge bushings, starting-motor parts.

No. 63. **Leaded Gun Metal.**—Bushings and bearings, fittings for moderately high water or oil pressures.

No. 64. **Phosphor Bronze.**—Wrist pins, piston pins, valve rocker-arm bushings, fuel and water-pump bushings, steering-knuckle bushings, aircraft control bushings, resistance to wear and scuffing.

No. 640. **Nickel Phosphor Bronze.**—Cones of synchronizer gears.

No. 65. **Phosphor Gear Bronze.**—Not regularly used.

No. 66. **Bronze Backing for Lined Bearings.**—Main bearings, connecting-rod bearings.

No. 67. **Semi-Plastic Bronze.**—Water-pump bearings.

No. 68. **Aluminum Bronze.**—Valve seats, worm wheels, gears, valve guides and forgings.

No. 70. **Commercial Brass Sheets.**—General purposes, gasoline tanks, oil tanks; radiator shells, trim rods, pipe, rivets, water-jacket plates, flat springs, deep drawings and stampings.

No. 71. **Copper Sheets.**—Minor parts such as connectors and terminals, cover plates, radiators, fittings on wing beams and struts.

No. 72. **Free-Cutting Brass Rods.**—Small screw-machine parts, pins, nuts, plugs, screws, valve disks, valve caps.

No. 73. **Naval Brass or Tobin Bronze Rods.**—Forgings, water-pump shafts, gears, gear bearings, propeller shafts, studs and nuts, bushings, turnbuckle barrels, adjusting strut ends, valve-stem bushings, screw-machine parts.

No. 74. **Annealed Seamless Brass Tubing.**—Brass water pipe, ignition tubes, foot-rest bars, radiator attachments and spacers, heaters, lighting plants.

No. 7. **Copper Tubing.**—Oil and fuel lines, oil-gage tube in lighting plants.

No. 76. **Naval Brass or Tobin Bronze Tubing.**—Bushings and bearings for starting motors and lighting plants.

No. 77. **Phosphor Bronze Strips.**—Grade A—friction plates in clutches, thrust washers, small springs, contact springs. Grade B—contact supports and springs, starting-switch springs.

No. 79. **Red Brass Sheets.**—Radiators; lamp shells, special drawing purposes.

No. 80. **Brass Wire.**—General purposes for springs, also for wrapping turnbuckles and locking wire.

No. 81. **Phosphor Bronze Wire.**—Minor springs.

No. 82. **Brass Wire.**—Safety wire for fastening nuts and bolts. (See also S.A.E. No. 80.)

No. 83. **Soft or Annealed Copper Wire.**—Electrical purposes, wire, and cable.

No. 88. **Brass Rods.**—Forgings, screws, and studs.

"Supplement to S.A.E. Handbook," issued August, 1934 by the Society of Automotive Engineers, New York.

Tempers of Sheet Brass

Brass finished by annealing is designated as follows:

Light anneal or blued.
Drawing anneal or blued soft.
Soft drawing anneal or soft.

The first-named terms have been adopted by the S.A.E. and the A.S.T.M. and are to be preferred.

Brass finished by rolling is designated according to the amount the thickness of the sheet is reduced from the original thickness. When the thickness is reduced one number by the Brown and Sharpe gage, the sheet is known as "¼ hard." The sheet tempers follow.

REDUCTION IN B. & S. GAGE NUMBERS	DESIGNATION OF TEMPER
1	¼ hard
2	½ hard
3	¾ hard
4	Hard
6	Extra hard
8	Spring
10	Extra Spring

Brass rods are usually drawn to what is called drill temper. It is produced by reducing the diameter from 5 to 10 per cent. Rods are also drawn "hard" by reducing the diameter from 12 to 20 per cent.

Tolerances allowed by the Chase Metal Works are: Sheets—0.00025 to 0.006 inch for Brown and Sharpe gages Nos. 38 to 0000 respectively; wire and rods—0.00025 inch for 0.025-inch rods to 0.010 inch for 3.5-inch rods; tubes—0.001 inch for 1-inch tubes of No. 26 gage to 0.031 inch for tubes 10 inches or over, of No. 0000 Stubs' gage.

Tolerances on Brass and Copper

Tolerances on sheet brass and copper depend on the width of the sheet as well as the thickness. On thicknesses from 0.460 to 0.324 inch (Nos. 0000 to 0) the tolerance is 0.005 inch on sheets up to 8 inches in width; 0.0055 inch on 8 to 11 inches in width; and 0.006 on width of 11 to 14 inches. The tolerances decrease to 0.000025, 0.0005 and 0.00075 inch respectively on sheets 0.0056 to 0.0040 inch thick (Nos. 35 to 38). These are Brown and Sharpe gage.

Wall thickness of seamless tubing is measured by Stubs gage. Tolerances vary both with wall thickness and with tube diameter. On tubes under 2 inches diameter with walls 0.454 inch thick, the tolerance is 0.019 inch. Tubes over 10 inches, with the same wall, are 0.031 inch. Tubes with a wall thickness of 0.083 inch have tolerances of 0.0045 inch for 2 inches and of 0.016 inch for 10 inches in diameter. Intermediate sizes and thicknesses vary in proportion. These tolerances are plus or minus (Chase Metal Works).

COMMON USES AND TEMPERS OF WROUGHT-COPPER ALLOYS

Straight Brasses

Common Mill Name	Approximate Composition		Form	Typical Uses	Usual Temper
	Cu	Zn			
Copper	100		Sheet	Radiator cores	Soft
				Electrical	¼ hard and soft
			Wire	Electrical purposes	Soft
			Tube	Heater coils	Soft
				Gasoline supply	Soft
				Marine work	Blued or half hard
Gilding	95	5	Sheet	Screw shells	Blued
				Inexpensive jewelry	Blued
Commercial bronze	90	10	Sheet	Radiator cores	Soft
				Screw shells	Blued
				Kick plates	¼ hard
			Wire	Screws	Screw
				Rivets	Rivet
Rich low brass	85	15	Sheet	Hardware	Blued
Low brass	80	20	Sheet	Ornamental work	Blued
				Clock dials	¼ hard
Cartridge brass	70	30	Sheet	Cartridges	Blued soft
				Musical instruments	Blued soft
				Brazed tubes	Soft
				Spinning	Soft
				Springs	Spring
			Tube (usually brazed)	Bedsteads	Half hard
				Plumbers' bends	Blued soft
High brass	67	33	Sheet	Deep drawing	Blued or blued soft
				Spinning	Soft
				Eyelet	Blued soft
				Radiator cores	Blued
			Tube	Pump liners	Half hard
				Miscellaneous	Blued or half hard
Common high brass	65	35	Sheet	Drawing	Blued and blued soft
				Blanking	¼ hard
				Stamping	Soft
				Spring	Spring
			Wire	Screws	Screw
				Rivets	Rivet
				Safety pins	Spring
Pin metal	62	38	Wire	Pins	Extra hard
				Soft wire	Soft
				Brazing	Soft
Muntz metal	60	40	Tube	Condensers	Condenser
				Miscellaneous	Blued or half hard

Leaded Brasses

Common Mill Name	Approximate Composition			Form	Typical Uses	Usual Temper
	Cu	Zn	Pb			
Leaded yellow....	66	32	0.8	Tube	For free turning	Half hard
Leaded high......	66	33.5	0.4	Tube	Miscellaneous	Blued or half hard
Butt brass.......	64	35.25	0.75	Sheet	Butts	Half hard
					Hinges	¼ hard
					Matrices	Hard
				Wire	Screw eyes	Rivet
Clock brass.... .	64	34	1¾	Sheet	Clock and watch backs, gears, etc.	Hard
Free turning......	61	36	3	Rod	Most screw-machine work	Drill
Forging..........	60	38	2	Rod	Hot forgings	Drill

Tinned Brasses

	Cu	Zn	Pb	Sn			
Commercial bronze rod.............	86	12½	1	½	Rod	Hardware	Drill
Admiralty.........	70	29		1	Tube	Condenser tubes	Condenser
Naval brass........	60	39		¾	Rod	Bolts and nuts	Drill
						Marine use	Drill
					Tube	Marine use	Blued

Nickel Silvers

	Cu	Zn	Ni			
5 per cent nickel...	64	31	5	Sheet	Trimmings	Blued
				Wire	Inexpensive jewelry	Blued
10 per cent nickel...	64	26	10	Sheet	Inexpensive jewelry	Blued
					Inexpensive tableware	Soft
18 per cent nickel...	64	18	18	Sheet	Tableware	Soft
					Drawing	Soft
					Spinning	Soft
					Base for most silver-plated ware	Soft

Low Melting Alloys

Low melting alloys are used extensively for securing punch and die parts, anchoring machine parts, short run forming dies, stripper plates, and similar work. For this work a metal known as *Cerromatrix*, melting at 250 degrees F., is largely used.

For proof castings in forging dies molds, gun chambers, etc., Cerrosafe, melting at 190 degrees F., is used.

An even lower melting metal, Cerrobend, melting at 158 degrees F., is used to fill thin walled tubes to prevent crushing when bending, and for some of the above mentioned uses.

APPROXIMATE AVERAGE PHYSICAL PROPERTIES OF WROUGHT-COPPER ALLOYS

Alloy	Composition				Density No. Cubic Inches	Tensile Strength		Per Cent Elongation		Scleroscope		Form in Inches
	Cu	Zn	Pb	Ni		Soft	Hard	Soft	Hard	Soft	Hard	Sheet
Copper...................	100				0.323	32,000	50,000	45	5	6	22	0.040
Gilding..................	95	5			0.320	34,000	52,000	45	5	6.5	24	0.040
Commercial bronze........	90	10			0.318	36,000	56,000	45	5	7	26	0.040
Rich low brass...........	85	15			0.315	39,000	61,000	55	9	8	28	0.040
Low brass................	80	20			0.313	42,000	66,000	62	12	9	32	0.040
Cartridge brass..........	70	30			0.308	44,000	68,000	70	11	9	32	0.040
High brass	67	33			0.306	43,000	67,000	70	10	9	32	0 040
Common high brass........	65	35			0.305	42,000	66,000	70	10	9	32	0.040
Pin metal................	62	38			0.304	48,000	75,000	50	5	11	35	0 040
Muntz metal..............	60	40			0.303	54,000	80,000	45	4	14	38	0.040
10 per cent Ni silver....	64	26		10	0.310	58,000	80,000	40	10	15	35	0.040
18 per cent Ni silver....	64	18		18	0.316	62,000	85,000	35	8	16	35	0 040
Forging brass............	60	38	2		0.305	50,000	65,000	45	20			1-inch rod
Free turning.............	61	36	3		0.306	45,000	62,000	60	15			1-inch rod
Naval brass..............	60	39	Sn 1		0.304	54,000	70,000	50	25			1-inch rod

BISMUTH ALLOYS (FUSIBLE METALS)

	Bismuth	Lead	Tin	Cadmium	Melting Point
					C°
Newton's alloys ...	50.0	31.25	18.75	—	95
Rose's " ...	50.0	28.10	24.64	—	100
Darcet's " ...	50.0	25.00	25.00	—	93
Wood's " ...	50.0	24.00	14.00	12.00	66–71
Lipowitz's " ...	50.0	27.00	13.00	10.00	60

ALLOYS

	Copper	Tin	Lead	Zinc	Nickel	Antimony	
Babbitt	8.	92.					
Bell metal	76.5	23.5					"Big Ben,"
	74.8	25.2					Westminster.
Brass	63–72			27–34			Typical brass.
" wire	70.29	0.17		29.26			
Britannia	1.46	90.62				7.81	Birmingham sheet.
Bronze........	95	4.		1.			British coinage.
	80–90	12–18		7.			Heavy bearings
German silver..	60			20.	20		Nickel varies.
Gun metal	91	9.					Cannons.
Mannheim gold	80–88			20–12			
Muntz metal ..	60–62			38–40			Ship sheathing.
Packfong......	43.8			40.6			Chinese alloy.
Shot metal			99.6		15.6		Trace of arsenic.
Speculum	70.24	29.11		trace			Telescope mirror.
Type metal....	2.0	10.	70			18.	
		3.2	82			14.	Stereotyping.
White metal ..	6.	82.				12.	For bearings.

ALLOYS FOR COINAGE

	Gold	Copper	Silver	Other Constituents	Remarks
Gold coin	91.66	8.33	—	—	British standard.
" "	90.0	10.0	—	—	"Latin Union" and American.
" "	1.33	82.73	15.93	—	Roman, Septimus Severus, 265 A.D.
" "	40.35	19.63	40.02	—	Early British B.C. 50.
Silver coin	0.1	7.1	92.05	Lead 0.2	Roman B.C. 31, almost same as British silver coin.
" "	—	7.5	92.5	—	British standard.

TABLE 25.—PROPERTIES OF METALS

Metal	Melting Point, °F.	Weight, Cubic Inches	Weight, Cubic Feet	Specific Gravity or Density		Chemical Symbol
				g/cm³	Degrees Cent.	
Aluminum	1220 ± 0.2	0.0975	168.5	2.702	20	Al
Antimony	1166.9 ± 0.2	0.241	417	6.684	25	Sb
Beryllium	2336 ± 72	0.066	114	1.83	20	Be
Bismuth	520.3 ± 0.2	0.354	611	9.80	20	Bi
Brass, cast (20 to 36 Zn)	1850 to 1706	0.303 to 0.311	523 to 538	8.39 to 8.63	20	
Bronze	1535 to 1832	0.315 to 0.321	545 to 554	8.74 to 8.89		
Chromium	3272 ± 90	0.256	443	7.1	.....	Cr
Cobalt	2714 ± 36	0.321	555	8.9	20	Co
Columbium	3632 ± 90	0.309	534	8.57	20	Cb
Copper	1981.4 ± 0.2	0.322	556	8.92	20	Cu
Gold	1954.4 ± 0.0	0.696	1,203	19.3	20	Au
Iridium	4449 ± 5	0.808	1,397	**22.4**	20	Ir
Iron, cast	2795 ± 5	0.260	450	**7.2**	20	Fe
Iron, wrought	2786	0.281 to 0.285	486 to 493	7.80 to 7.90	.....	
Lead	621.3 ± 0.2	0.409	707	11.34	20	Pb
Magnesium	1202 ± 4	0.063	109	1.74	20	Mg
Manganese	2300 ± 36	0.260	449	7.2	20	Mn
Mercury	−37.97 ± 0.04	0.512	885	14.19	−38.9	Hg
Nickel	2651 ± 2	0.321	555	8.90	20	Ni
Molybdenum	4757 ± 90	0.365	630	10.11	20	Mo
Platinum	3224 ± 2	0.774	1,338	21.45	20	Pt
Silver	1760.9 ± 0.0	0.379	655	10.5	20	Ag
Steel, cast Steel, rolled	2714 to 2768	0.274 to 0.281	474 to 486	7.60 to 7.80		
Tantalum	5432 ± 180	0.598	1,033	16.57	20	Ta
Tin	449.4 ± 0.2	0.264	456	7.31	20	Sn
Tungsten	6170 ± 36	0.696	1,203	19.3	.....	W
Vanadium	3155 ± 90	0.215	372	5.96	.....	V
Zinc	787.1 ± 0.2	0.258	445	7.140	20	Zn

Bureau of Standards.

[1] Cubic feet of water at 4°C. = 62.3565 pounds; weight per cubic inch = 0.036086 pound.

SHRINKAGE OF CASTINGS

Aluminum—pure	.2031	in./ft.
" Nickel Alloy	.1875	"
" Special Alloy	.1718	"
Iron, Small Cylinders	.0625	"
" Pipes	.125	"
" Girders and Beams	.100	"
" Large Cylinders, Contraction of Diam. at Top	.0625	"
" Large Cylinders, Contraction of Diam. at Bottom	.083	"
" Large Cylinders, Contraction of Length	.094	"
Brass—Thin	.167	"
" Thick	.150	"
Copper	.1875	"
Bismuth	.1563	"
Lead	.3125	"
Zinc	.3125	"
Magnesium	.1875	"
	.28125	"

METALS USED IN DIE CASTING

The metals used in die castings are limited by certain requirements peculiar to the process. Either they must not be subject to excessive shrinkage at high temperatures, or else they must be sufficiently strong to withstand the shrinkage. Unless one of these two conditions is met, the castings will crack before they can be removed from the die. For example, an alloy of aluminum and zinc, while common in sand casting, is not suited to die casting, although an alloy of aluminum and copper can be die-cast successfully. The metals used must not be such as will attack the surface of the die. It has been found that an alloy of copper and aluminum can be cast in permanent molds, while an alloy of copper and zinc, fusing at no higher temperature, will seriously injure the surface of the mold. The metals must fuse at a temperature low enough to avoid destroying the section of the casting machine in which the molten metal is contained, at least for a reasonable length of time. This condition has so far been one of the chief handicaps to the use of aluminum bronze in the production of die castings.

Die-casting alloys, in general, may be divided into four groups:

1. Zinc-Base Alloys.—These were early used in die casting, and are still employed to a large extent in the production of

	Per Cent	Per Cent
Tin	6	None
Copper	3½	3
Aluminum	1¼	5
Zinc	89¼	*92

* Horsehead spelter or its equivalent should be used in this alloy, or, in fact, any zinc alloy where the aluminum content is higher than 1½ per cent.

many types of parts on account of their adaptability in taking accurate shapes when forced into the die under pressure. The two mixtures shown in the table at the bottom of page 1074 are representative of the alloys of this class now in use.

2. **Tin-Base Alloys.**—These are more generally known as babbitt metals. They have become of special use in the production of automobile bearings and have also become commonly used in connection with various parts requiring acid-resistant or non-corrosive properties. The following mixtures are representative of this class:

	Per Cent	Per Cent	Per Cent	Per Cent
Tin	87	84	81½	78½
Antimony	7	9	13¾	13¼
Copper	6	7	4¾	4¼
Lead				4

3. **Lead-Base Alloys.**—These are alloys containing a high percentage of both tin and lead. They are also used for bearings, but only where the speed is slower and the heat conditions are less severe, for example, in stationary engines. The following alloys may be considered representative:

	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent
Lead	25	42	67½	75	84½
Tin	61½	48	17	15	5
Antimony	10½	8½	15	10	10
Copper	3	1½	00½	00	00½

4. **Aluminum-Base Alloys.**—They may be divided into various groups: aluminum copper, aluminum silicon, aluminum copper silicon. Other elements, such as magnesium, manganese, and nickel, are sometimes introduced to give special color, toughness, or wearing qualities.

In considering the various alloys used in die casting, the limits of weight, accuracy, and other properties possible in each are of interest. They may be classified approximately as follows:

LIMITS,* MAXIMUM WEIGHTS FOR CASTINGS

	POUNDS
Aluminum-base	3
Tin-base	8
Lead-base	10
Zinc-base	6

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* These limits may sometimes be exceeded where the nature of the part is favorable to die casting.

Limits, Minimum Wall Thickness

	Inc
Lead-base	$\frac{1}{32}$
Tin-base	$\frac{1}{32}$
Zinc-base	$\frac{1}{8}$ (on small castings) $\frac{1}{16}$
Aluminum-base	$\frac{1}{8}$ (on small castings) $\frac{1}{16}$

Possible Variations from Drawing Dimensions, per Inch of Diameter or Length

	Inch
Lead-base	0.001
Tin-base	0.0005
Zinc-base	0.001
Aluminum-base	0.0025

Where the distance involved is several inches, these limits may sometimes be reduced.

Maximum Number of Threads

Lead-base, external	24 per inch
Zinc-base, external	30 per inch
Tin-base, external	34 per cent
Aluminum-base, external	20 per inch

In the case of aluminum, where close fit is required, the threads should be cast oversize and chased. Where economical, internal threads may be cast in parts made from zinc-, tin- or lead-base alloys, but this is seldom possible in parts made of aluminum.

Holes

Lead-base, tin-base, and zinc-base, $\frac{1}{32}$ inch minimum. Regulated by depth of hole and thickness of casting.

Aluminum-base, $\frac{3}{32}$ inch minimum. Size of hole is dependent on its length and the general design of castings. Holes not cast can usually be spotted to facilitate drilling.

Draft

Lead-base and tin-base. Cores 0.0005 inch per inch of length and diameter. Side walls 0.01 inch per inch.

Zinc-base. Cores 0.001 inch per inch of diameter and length. Side walls 0.001 inch per inch.

Aluminum-base. Cores 0.015 inch per inch of length and diameter. Cores less than $\frac{1}{4}$ inch in diameter should have 0.005 inch draft per inch of length. Side walls 0.005 inch per inch. It is sometimes possible to modify these limits when they interfere with the service required.

Brass Die Castings

After much experimenting, die castings are now made successfully in brass, white-nickel brass, and manganese bronze. These pressure die castings are about three times as strong as sand castings of 60-40 brass. "Brastil," the name of Doehler brass pressure castings, has a tensile strength of 90,000 pounds. It is easily machined and makes a good bearing.

ALLOYS FOR SPECIAL PURPOSES

Alcumite

Alcumite is a non-ferrous alloy with a golden appearance. It melts at approximately 1900°F. and remains strong and ductile up to about 1600 degrees. Ultimate tensile strength is about 75,000 pounds, cast elongation, about 25 per cent. In rolled form the tensile is 100,000 to 110,000 pounds per square inch, and the elongation, 30 to 40 per cent. It resists sulphuric and most other corrosive acids and gases.

Alcumite is an aluminum bronze alloy with a copper base and some iron, manganese and nickel. It is malleable, can be machined at 80 feet per minute, and welded. It can be cast and forged. Specific gravity 8.3; weight per cubic inch is 0.299 pound; it melts at 1900°F.; shrinkage is $\frac{3}{16}$ per foot. Brinell hardness is 130 for castings, 195 for hot-rolled sheets. Tensile strength is 75,000 pounds for castings, 110,000 pounds for hot-rolled sheets.

Aluminum

Can be melted in ordinary plumbago crucibles, like brass, and will not absorb silicon or carbon to injure it unless overheated. Melts at 1217°F. or 625°C. Becomes granular and easily broken at about 1000°F. From 0.5 to 2 per cent.

Shrinkage of pure aluminum...	0.2031 inch per foot
Nickel-aluminum casting alloy.	0.1875 inch per foot
Special casting alloy..........	0.1718 inch per foot

The most used alloys have a strength of about 20,000 pounds to the square inch at a weight of one-third that of brass.

Iron or sand molds can be used and the metal should be poured as cool as it will run to avoid blowholes.

Burnishing.—Use a bloodstone or steel burnisher, with mixture of melted vaseline and kerosene oil or two tablespoonfuls of ground borax, dissolved in a quart of hot water and a few drops of ammonia added.

Frosting.—Clean with benzine. Dip in strong solution of caustic soda or potash, then in solution of undiluted nitric acid. Wash thoroughly in water and dry in hot sawdust.

Polishing.—Any good metal polish that will not scratch will clean aluminum. One that is recommended is made of 1 part of stearic acid, 1 part of Fuller's earth, and 6 parts of rotten-stone; grind fine and mix very well.

Castings are cleaned with a brass scratch brush run at a high speed. Sand blasting is also used both alone and before scratch brushing.

Spinning.—A high speed, about 4,000 feet per minute, is best for spinning. This means that for work 5 to 8 inches in diameter, 2,800 to 2,600 revolutions per minute is good, while for smaller work of 4 inches this would go up to 3,200 r.p.m.

Turning.—Use a tool with shearing edge similar to a wood-cutting tool, as they clear themselves better. Use kerosene or water as a lubricant, or if a bright cut is wanted, use benzine. For drawing on a press use vaseline.

Ascoloy

Ascoloy is a chromium-steel alloy sometimes called "rustless iron." It can be machined in about the same way as high-carbon steel and can be welded by either oxyacetylene or arc, although the former is preferred. Tensile strength annealed is 80,000 pounds; properly heat-treated, it has shown 200,000 pounds. It has a Brinell up to 364; good for use in mines.

Bakelite

Bakelite is a synthetic product formed from formaldehyde and phenol or carbolic acid, which form a resin-like material which hardens with heat. It is molded into many forms, and by impregnating sheets of paper or cloth with the resin and baking it under pressure, a very strong sheet is produced. Gears are made from sheets made up of strong cotton duck and bakelite and give quiet service and long life. Specific gravity is 1.35. Tensile strength of average products is 13,000 pounds; of molded products, 4,500 pounds.

Calite

Calite is a heat-resisting alloy in which nickel and aluminum are the principal alloys. It is used for carburizing boxes and similar purposes. Cast calite cannot be machined or cut with the oxyacetylene torch. All finish is by grinding. It also resists corrosion from salts.

PHYSICAL PROPERTIES

Melting point	2777 degrees Fahr.
Softening point	2500 degrees Fahr.
Working temperature	2200 to 2370 degrees Fahr.
Specific gravity	7.03
Weight per cubic inch	0.25 lb.
Tensile strength	36,800 pounds per square inch
Brinell hardness, annealed	286
Scleroscope	40

Duralumin

Duralumin is an aluminum alloy that has the advantage of being approximately one-third the weight of steel, or 0.101 to 0.103 pound per cubic inch. It can be supplied in various types and sections ranging from plates and sheets to angles and tubes, and can be cast, forged, or stamped so that it may be used for a variety of parts. Duralumin is the trade name of the product, and similar metals are made under other names carrying the same characteristics.

COMPOSITION

The composition of the finished alloy can be stated as follows:

	PER CENT
Copper	3.5–4.0
Manganese	0.5–0.75
Magnesium	0.5–1.00
Silicon	Under 0.60
Iron	Under 0.60
Aluminum	Balance

Silicon and iron are generally impurities. The form in which the raw material is used is important and can be stated as follows:

Ingot aluminum	over 99 per cent purity
Copper-aluminum alloy	Copper 50 per cent Aluminum 50 per cent
Aluminum-magnesium	Aluminum, 90 per cent Magnesium, 10 per cent
Aluminum-manganese	Aluminum, 90 per cent Manganese, 10 per cent

ANNEALING

Temperatures to which duralumin is subjected must be carefully watched and checked by the use of accurate pyrometers. The secret of good Duralumin lies entirely with the accurate temperatures used in alloying and in heat-treatments. Annealing should be done between the temperatures of 660 and 715°F., and cooled in air. At this temperature the metal becomes plastic and can be worked and formed into various shapes. The purpose of annealing is to increase the softness and ductility, so that it may be more easily formed into various shapes, such as stampings, also that it may withstand the strains to which it is to be subjected.

HEAT-TREATMENT

The tempering of Duralumin consists of immersing the metal parts in a salts bath, heated to a temperature of 895 to 930°F., then quenching in boiling water. The salts employed are potassium nitrate and sodium nitrate in equal parts. An important point is the period of time necessary for the material to remain in the bath. For annealing plates from 0.04 to 0.08 inch thick, 10 to 20 minutes at 660°F. are required, and for tempering, the time is from 7 to 16 minutes at 930°F. The methods of heating are by electricity, gas, or oil. Charcoal or coke should never be used, because the gases given off, if they should combine with the nitrates used in the bath, would result in a highly combustible and explosive compound.

MACHINING

Duralumin can be turned and machined at practically the same speed and feed as brass. It does not seize or drag the tools as do some aluminum alloys. Kerosene forms a good tool lubricant in threading or finishing parts, leaving a clean-cut surface. A mixture of lard oil and kerosene, in equal parts, will be found useful for average work. When buffed, Duralumin takes a fine polish similar to silver, except that the surface lasts longer, as it does not tarnish in the presence of sulphureted hydrogen and similar gases.

Everdur Metal No. 50

Everdur is an alloy of copper, silicon, and manganese and compares physically with medium carbon steels, but resists corrosion. Specific gravity, cast, is 8.15, weight per cubic inch is 0.294 pound. Tensile strength, castings, is 50,000; small, hard-drawn wire, 157,000 pounds. Melting point is 1922°F. It machines similarly to high-grade bronze, and can be welded by either process.

Genelite

Genelite is a spongy bronze with about 40 per cent, by volume, of graphite uniformly distributed in it. Its spongy nature permits it to absorb about 3 per cent in weight or 20 per cent in volume, of oil. It is a bearing metal for piston-pin bushings and similar places. It is difficult to cut as it dulls tools rapidly but can be easily ground with the proper wheels. It should be completely supported because it springs easily.

Monel Metal and Inconel

Monel metal is a trade name of a metal which is now made in three grades. Monel is two-thirds nickel and one-third copper. It is a general-purpose metal that is rustproof, corrosion-resistant, and has a yield strength of from 25,000 to 115,000 pounds. "K" Monel is 66 per cent nickel, 29 per cent copper, and 2.75 aluminum. It is nonmagnetic and can be heat treated to 145,000 pounds yield point. "R" Monel is 67 per cent nickel, 30 per cent copper, and has 0.035 per cent sulphur. It is free-machining and has a yield point about 10,000 below Monel. Inconel, which is produced by the same firm, is 79 per cent nickel, 13 per cent chromium, and 6 per cent iron. It is both heat- and corrosion-resistant, with yield points up to 140,000 pounds.

Monel metal shrinks $\frac{1}{4}$ inch to the foot in castings; should be poured at 2800°F. Cores should be made of washed silica sand and raw linseed oil, in the proportion of about 25:1 for large cores and 60:1 for small cores.

PICKLING

For heavily scaled Monel soak in 10 per cent (by weight) hydrochloric acid for 30 minutes at 180°F., then dip in a sodium dichromate solution for 5 to 10 minutes at room temperature. This solution is made by dissolving 0.1 gallon of sulphuric (66°Bé.) and 1.1 pounds sodium dichromate in 1 gallon of water. For unscaled Monel the solution is 1 gallon of water, 1.5 gallons sulphuric acid 66° Bé., 2.2 gallons nitric acid 38° Bé.; cool, and add 0.2 pound sodium chloride.

WELDING

Monel metal welds readily by gas or electric method. Monel rods should be used. Welding tip should be one size larger than for steel. An electric welding flux has been specially developed. Monel metal rods make a machinable weld on cast iron. Monel metal is easily soldered and brazed; clear surfaces are necessary.

DRAWING AND PUNCHING

Reduction of diameter and depth of draw about as for steel, but corners of dies should have larger radius to prevent tearing. Metal is "sticky" and tends to adhere to soft dies. Diameter of first cup is usually about two-thirds that of blank. Reduction of 30 per cent in gage may be had in one draw with slight reduction in diameter. Clearances are usually greater than for steel; runs 0.010 to 0.015 inch on metal from 0.1021 to 0.078 inch. Greater power required than with steel. Proper adjustment of pressure plate and blank holder prevents wrinkling. Anneal at 1400 degrees between draws. Punches are designed about 75 per cent stronger than for steel, with same clearance angles.

SPINNING

Owing to toughness, Monel metal is harder to spin than copper, brass, steel, or silver and requires more frequent annealing. Spinning tools should be brass, bronze, wood, or tool steel, not soft steel. Lubricate with tallow. No change necessary from ordinary speed of lathe.

Bakelite

Bakelite is made under a variety of names such as "Dilecto," "Formica," "Insurok," "Lamicoid," "Micarta," "Panelyte," "Phenolite," "Spauldite," and "Synthane." Sheet stock weighs 0.78 ounce per cubic inch, or 20.5 cubic inches weighs 1 pound. Specific gravity is 1.32 to 1.40. Suggestions as to machining are: Use saws just soft enough to file; band saws should have 5½ teeth per inch and run 4,000 feet per minute; circular saws can run 6,000 feet per minute.

Gear Shaping.—Use 100 to 130 strokes per minute roughing with fairly fine feed; for finishing, use 500 strokes per minute with 0.010-inch stock left for finish.

Milling.—Use high speed and coarse feed. Give tools 3 to 5 degrees more rake than for metal. Where possible, remove all material at one cut. No cut should be less than ⅛ inch.

Drilling.—Use high-carbon steel drills. Holes will normally be about 0.003 inch under size. To get a larger hole, grind the drill off center. Use highest speed without burning and withdraw from work quickly. Holes $\frac{3}{16}$ and smaller are drilled dry; use lubricant with larger holes. Special drills can be had for this work.

Threading.—Taps and dies used on metal are suitable if used with lubricant.

Punching.—Plain punches and dies suitable up to $\frac{1}{8}$ inch diameter. Keep sharp, and use minimum clearance. Material should be heated to about 280°F. on steam table. Sheets $\frac{1}{8}$ to $\frac{3}{8}$ inch should be blanked out and then shaved. Work should be heated and oiled. Shaving cutters should have 45 degrees rake. Heavier stock should be sawed out and machined in lathe or milling machine.

Shearing.—Heat to 120 to 300°F. to prevent chipping of edge.

Dull Finish.—Rub with pumice; then with oil. For a dull matt use No. 0 emery cloth, finish with No. 00. For electrical work use sandpaper.

Tapping Laminated Plastics

Taps wear rapidly in laminated plastics as holes contract and bind in backing out. Carbon steel taps may tap 300 to 400 holes and high-speed taps double that number. Ground thread, high-speed taps when properly chromium plated will tap 1,000 to 1,200 holes and can be sharpened and replated from nine to twelve times. Thread relief should be greater than for metals. Compressed air jets are the best "lubricant." Recommended tapping speeds for laminated plastics are given in the table below.

TAPPING SPEEDS FOR LAMINATED PLASTICS

Diameter of Tap, in Inches	Revolutions per Minute	Surface Speed Feet per Minute
0.0590	3,500	54
0.0787	2,575	53
0.0984	2,020	52
0.1181	1,650	51
0.1378	1,390	50
0.1575	1,165	48
0.1772	993	46
0.1968	855	44
0.2165	742	42
0.2362	647	40

SOME USES OF LEAD

Sheet lead can be molded and united by soldering, welding, or burning. It is used for such work as roofing, flashing, valleys, water caps, etc. It is also used for lining tanks and acid containers where the corrosive effects of acids must be resisted.

Lead burning, or autogenous soldering, is the process of joining two edges of the metal by fusion or melting without the use of any other metallic alloy. The union is accomplished by directing an oxyhydrogen flame upon the two surfaces or edges to be joined. By this process the possibility of cracking or breaking apart is practically eliminated, and the pliability of the lead is maintained. Lead burning is advantageous in chemical works for joining the edges of sheet lead for sulphuric chambers, tanks, vats, and concentrating pans, where solder containing tin would corrode.

Lead wire and rods are used by engineers for testing bearings and filling inequalities in surfaces. It runs from 22 Birmingham gage to $\frac{9}{16}$ inch. Lead washers are used extensively for gas, water, and electrical work and for similar work where it is desirable that the washer conform closely to the uneven surface. These are usually flat on both sides. For building and roofing purposes they are concave and are useful for preventing leaks in steel roofs and side walls.

Antimonial lead, sometimes called "hard lead," consists of pure lead with addition of antimony to provide stiffness. If the percentage of antimony is not too high, there is no change in the desirable properties of the lead. Excessive use of antimony in lead adds to the possibility of cracking, and the lead thus brittleized is difficult to handle and work. The hardness of antimonial lead is a desirable feature when made up into sheets and makes it especially desirable for lining deep tanks. Its hardness prevents it from being injured in contact with materials or equipment. Approximate tensile strength is double that of pure lead, and lighter weight sheets can therefore be used. American Smelting and Refining Company supplies sheets with percentages of antimony up to 7, but recommends 3 to 4 per cent antimony.

INDUCTION HEATING

Heating metals by high frequency current dates back to 1916, but has only recently come into use in production. Among its advantages are that heat can be localized and that the heating period is so short that both distortion and oxidization are minimized. Properly designed fixtures make it possible to secure uniform and highly satisfactory results with a minimum of training.

SALT BATHS FOR ALUMINUM*

Sodium nitrate—or this plus potassium nitrate, equal parts—melts below annealing temperature. For rivets, avoid contact with salts. The rivet containers may be put in metal tubes with caps and handles made 2 to $2\frac{1}{2}$ inches in diameter to hold them. The top of the tube should be at least 4 inches below the salt bath. Quench in water 85 to 100°F.

* Army-Navy practice, adopted July 25, 1942.

SECTION XXII

MACHINE FORGINGS

STEAM HAMMERS

While it is impossible accurately to rate the capacity of steam hammers with respect to the size of work they should handle, on account of the greatly varying conditions, a few notes from the experience of the Niles-Bement-Pond Company will be of service.

For making an occasional forging of a given size, a smaller hammer may be used than if we are manufacturing this same piece in large quantities. If we have a 6-inch piece to forge, such as a pinion or a short shaft, a hammer of about 1,100 pounds capacity would answer very nicely. But should the general work be as large as this, it would be very much better to use a 1,500-pound hammer. If, on the other hand, we wish to forge 6-inch axles economically, it would be necessary to use a 7,000- or 8,000-pound hammer. The following table will be found convenient for reference for the proper size of hammer to be used on different classes of general blacksmith work, although it will be understood that it is necessary to modify these to suit conditions, as has already been indicated.

Diameter of Stock	Size of Hammer
3½ Inches	250 to 350 pounds
4 Inches	350 to 600 pounds
4½ Inches	600 to 800 pounds
5 Inches	800 to 1,000 pounds
6 Inches	1,100 to 1,500 pounds

Steam hammers are always rated by the weight of the ram and the attached parts, which include the piston and rod, nothing being added on account of the steam pressure behind the piston. This makes it a little difficult to compare them with plain drop or tilting hammers, which are also rated in the same way.

Steam hammers are usually operated at pressures varying from 75 to 100 pounds of steam per square inch and may also be operated by compressed air at about the same pressures. It is cheaper, however, in the case of compressed air to use pressures from 60 to 80 pounds instead of going higher.

In figuring on the boiler capacity for steam hammers, there are several things to be considered, and it depends upon the number of hammers in use and the service required. It will vary from 1 boiler horse-power for each 100 pounds of falling weight up to 3 horse-power for the same weight, according to the service expected. In a shop where a number of steam hammers are being used, it is usually safe to count on the lower boiler capacity given, as it is practically safe to say that all of the hammers are never in use at the same time. In a shop with a single hammer, on the other hand, and especially where hard service is expected, it is necessary to allow the larger boiler capacity since there is no reserve to be drawn on, owing to part of the hammer's being idle, as in the other case.

DROP FORGINGS

Draft in Drop-Forging Dies

In sinking dies for drop forging, it is important that the draft at the sides of the impression should be made as small as possible to avoid heavy cuts in the machining operations. It is equally important that the draft be sufficient to allow the forging to be easily withdrawn from the die, else production under the hammer will be hampered. The standard draft (or draw) for most dies is 7 degrees from the perpendicular, but other angles are used in special cases and sometimes two or three different angles of draft are used in the same die at different parts of the impression.

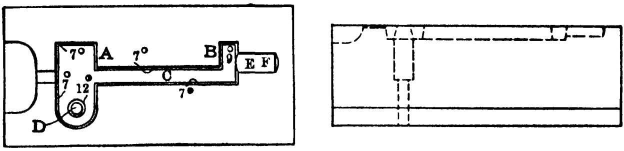

FIG. 1.—Example of Draft in Drop-Forging Dies

Figure 1 shows the plan and side elevation of a lower die where three angles of draft are advisable. The shoulders *A* and *B* are places where the metal is likely to hug on account of the contraction of the hot metal along the part marked *C*, which is of comparatively small cross section and will cool rapidly. These shoulders are given an angle of 9 degrees. The inserted tool-steel plug *D* is another place where metal is likely to hug badly. It is usual to give such plugs 12 and even 15 degrees of draft on each side. Moreover, the tendency of plugs to get "jumped up," hammered over, and badly heat-checked is much reduced if they are given a big draft. The part marked *E* is semicircular and will draw easily. The end of *E* at *F* is a part of a sphere. All other sides of the impression are given 7 degrees draft. If the die is smooth and regular the forging will draw easily.

All impressions are laid out to $\frac{1}{8}$ inch to the foot shrink rule. This allows for a shrinkage of about 0.010 inch to the inch. The same shrinkage is allowed in the thickness of forgings. For example: A forging is to be 2 inches thick with half the thickness in each die. The depth of impressions will be 1.010 inch in each die. In laying out the impression on the face of the die, allowance has been made for shrinkage in length, thickness, and breadth of forging, and, in addition, for the draft on the sides. In complex dies where there are many different depths and offsets on the face of the die, the die sinker has to keep all these points constantly in mind while laying out or run the risk of spoiling the whole job.

DRAFT DIMENSIONS

The allowance for 7-degree draft is easy to remember, being almost eactly $\frac{1}{32}$ inch at the face of the die for each $\frac{1}{4}$ inch of depth. Table 1 has been calculated to give the allowance in thousandths of an inch on actual depth, as measured with an ordinary depth gage. It is not usual in marking out to work closer than $\frac{1}{64}$ inch, but the arrangement of the table in thousandths allows the nearest $\frac{1}{64}$ inch to be taken. The best plan is to take the allowance for the angle at 1 inch depth as a constant and figure out the allowance for the particular depth wanted from the expression

TABLE 1.—ALLOWANCE IN THOUSANDTHS OF AN INCH AT FACE OF DIE FOR STANDARD ANGLES OF DRAFT AND VARIOUS DEPTHS OF IMPRESSION

Depths in Inches	STANDARD DRAFT ANGLES IN DEGREES			
	5 Degrees	7 Degrees	9 Degrees	12 Degrees
	Inch	Inch	Inch	Inch
1/8	0.011	0.015	0.020	0.027
1/4	0.022	0.031	0.040	0.053
3/8	0.033	0.046	0.059	0.080
1/2	0.044	0.061	0.079	0.106
5/8	0.055	0.077	0.099	0.133
3/4	0.066	0.092	0.119	0.159
7/8	0.077	0.107	0.139	0.186
1	0.087	0.123	0.158	0.213
1 1/8	0.098	0.138	0.178	0.239
1 1/4	0.109	0.153	0.198	0.266
1 3/8	0.120	0.169	0.218	0.292
1 1/2	0.131	0.184	0.238	0.319
1 5/8	0.142	0.200	0.257	0.345
1 3/4	0.153	0.215	0.277	0.372
1 7/8	0.164	0.230	0.297	0.399
2	0.175	0.246	0.317	0.425

$$\text{Draft allowance} = \frac{CD}{1}$$

where C = a constant and D = the depth in inches.

MAKING TYPES

A type, shown in Fig. 2, is generally used as a guide for chipping and scraping out the spherical end of the semicircular part. It is not usual to make the curve on the end conform to any particular mean angle of draft. Most diesinkers merely turn the end of the type to a curve that looks right to the eye. However, uniformity is desirable in these curves and Table 2 is given as a help in that direction. It gives the values of the mean angle of draft with various radii expressed in terms of the diameter of the type. It will

TABLE 2.—MEAN DRAFT OF SPHERICAL END OF CYLINDRICAL TYPE

When Radius of End of Type is	Mean Angle of Draft in Degrees is
2½ × Diameter of Type	5¾
2¼ × " " "	6½
2 × " " "	7¼
1¾ × " " "	8¼
1½ × " " "	9½

be noted that if the radius *r* is made twice the diameter of the type, the mean angle of draft is 7¼ degrees. This rule is easy to remember and a good one to adopt as standard. A good and easy way to get a close approximation to the required curve is as follows: Turn a cylinder of tool steel to the required diameter. Face the end square, scratch off the distance *GH* equal to the allowance for draft obtained from Table 1, remembering that the depth is half the diameter of the type. Turn the end to a curve which is uniform to the eye from the center to the scratched line *H*. After the type is hardened it is ready for use.

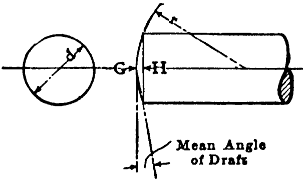

FIG. 2.—"Type" for Die Draft

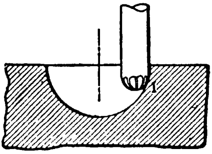

FIG. 3.—Diesinking Cutter at Work

Semicircular impressions are finished with ball cutters of the correct diameter. When a ball cutter of the correct diameter is not at hand and the job will not warrant making one, the following method may be used. The center line of the impression is projected to the end of the die. A semicircle is scribed on the vertical surface of the end. After the impression is roughed out, a smaller ball cutter is placed in the chuck of a diesinking machine and the knee and slides manipulated until the cutter is in proper relation to the semicircle as shown in Fig. 3. A square is used to indicate when the curves of cutter and semicircle are coincident, as at *I*. The micrometer dials are now set, the lateral slide locked, the knee lowered, the longitudinal slide operated until the cutter is in position over the impression and the ball tool sunk into the die until the micrometer comes to the position set at the semicircle on the end. A longitudinal cut is taken with this setting. The cutter is then placed in another lateral position and the operation of setting and cutting repeated. It may be necessary to perform this operation several times, and even then the result will be a series of gutters and ridges instead of a uniform, semicircular depression. This can be readily corrected with the scraper and riffler.

An aid in testing the accuracy of semicircular impressions is shown in Fig. 4. If the semicircle is true, the corners of the square will touch in all positions when the sides are resting on the edges of the impression. If the square rocks on the corner in any position, that spot is high and must be scraped down. This test must be made before the 'flash" is milled in the die.

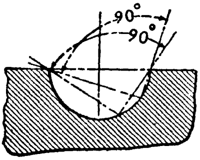

FIG. 4

Swaging

Swaging is also called "swedging" in some localities and is a forging process which is usually done cold, by a large number of repeated blows acting on a revolving die which shapes the work. While swaging is usually confined to comparatively small sizes, some automobile axle ends are shaped by this method. These are swaged hot and are held within very close limits. This process saves the metal that would be wasted in chips. The capacity of a machine is usually about half as much on solid work as on tubing of the same size. The power required varies from ½ horse-power on machines for ⅜-inch tubing to 7½ horsepower for 2-inch tubing.

Forging Hammers

Improved alignment and quick return in modern forging hammers, has, according to R. E. W. Harrison, made possible the reduction of draft in dies from 7 to 3 degrees in many cases. This materially reduces the amount of metal to be removed in machining. Factors which govern the selection of the correct size and capacity of forging hammers are:

1. Required die-face area (governing ram and cap face areas).
2. Total cubic inches displacement of metal to be effected (governs the power required in the tool).
3. Amount of preliminary drawing, fullering, and bending (governing type of tool—steam, air, or board).
4. Thin-section forgings which naturally cool rapidly can generally be made more economically on board hammers because of lower maintenance cost occasioned by relative ability of the board-type hammer to adapt itself to the load. (Board hammers are available up to 5,000 pounds capacity.)
5. Weight of die to be manipulated (has bearing on amount of power required).
6. Possible multiplicity of impressions in the dies (has bearing on size of ram).
7. Availability of different sources of power (air, steam, electricity, or line shaft).
8. Economic balance between size capacity of tool and anticipated work load. (Continuous production usually justifies a heavier tool.)
9. On high-production forging work it has been shown to be economically desirable to keep the ratio of falling weight to anvil assembly at not less than 25:1.

Drop-Forging Data[1]

With a lever such as shown in Fig. 5, the designer decides on a parting line (*PL*) which establishes all the formation above the parting line as being sunk or formed in the face of one die block and the balance in the companion die block. Although many pieces can be sunk with flat faces because the *PL* is straight, in the case of the lever shown, the *PL* must change from one level to another to part through the centers of the $\frac{7}{16}$ inch diameter and the $\frac{5}{16}$ inch radius and to clear properly. This creates a locked die, meaning that the die faces which carry the impression are of irregular topography.

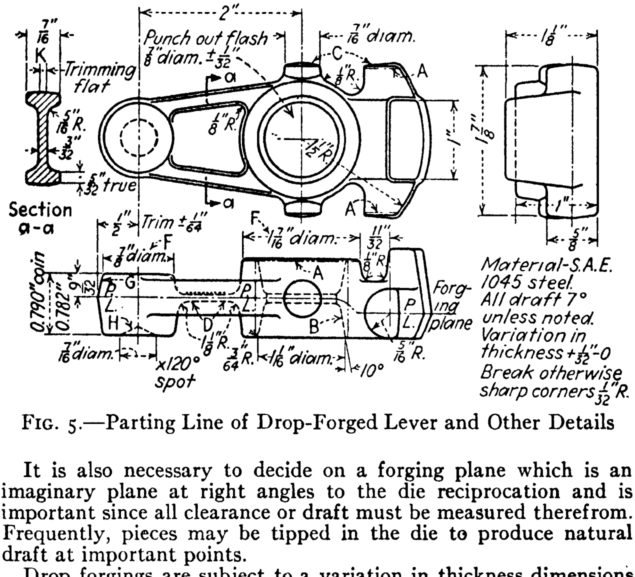

FIG. 5.—Parting Line of Drop-Forged Lever and Other Details

It is also necessary to decide on a forging plane which is an imaginary plane at right angles to the die reciprocation and is important since all clearance or draft must be measured therefrom. Frequently, pieces may be tipped in the die to produce natural draft at important points.

Drop forgings are subject to a variation in thickness dimensions (all dimensions perpendicular to the forging plane) amounting to 0.015 inch on very small forgings to $\frac{3}{16}$ inch on very large forgings. The variation on the average small forging is $\frac{1}{32}$ inch which may be regarded as plus $\frac{1}{32}$ inch minus 0 or plus or minus $\frac{1}{64}$ inch, or plus 0 minus $\frac{1}{32}$ inch. Lengths of forgings may vary as much as plus or minus 0.003 inch per inch of length. Maximum permissible tolerances should be indicated wherever possible. Surfaces of parts to be machined or ground should show or specify allowances for finish, usually $\frac{1}{32}$ to $\frac{1}{16}$ inch on a surface, but as little as $\frac{1}{64}$ inch on very small pieces and as much as $\frac{1}{8}$ inch on very large forgings. If the surface also carries draft, the draft is considered additional

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[1] J. H. Williams Company.

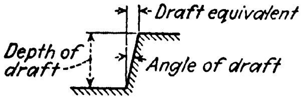

TABLE 3.—DIE-DRAFT EQUIVALENTS

Depth in Inches	Angle of Draft		
	5 Degrees	7 Degrees	10 Degrees
1/32	0.0027	0.0038	0.0055
1/16	0.0055	0.0077	0.0110
3/32	0.0082	0.0115	0.0165
1/8	0.0109	0.0153	0.0220
5/32	0.0137	0.0192	0.0276
3/16	0.0164	0.0230	0.0331
7/32	0.0192	0.0269	0.0386
1/4	0.0219	0.0307	0.0441
9/32	0.0246	0.0345	0.0496
5/16	0.0273	0.0384	0.0551
11/32	0.0301	0.0422	0.0606
3/8	0.0328	0.0460	0.0661
13/32	0.0355	0.0499	0.0716
7/16	0.0383	0.0537	0.0771
15/32	0.0410	0.0576	0.0827
1/2	0.0438	0.0614	0.0882
9/16	0.0492	0.0691	0.0992
5/8	0.0547	0.0767	0.1102
11/16	0.0601	0.0844	0.1212
3/4	0.0656	0.0921	0.1322
13/16	0.0711	0.0998	0.1433
7/8	0.0766	0.1074	0.1543
1	0.0875	0.1228	0.1763

thereto. Phantom lines are shown at the points marked *A* on the accompanying lever to indicate the machined surfaces.

The standard draft angle is 7 degrees around all exterior surfaces. Interior draft, such as holes in the forgings, which form frustums of cones in dies, as at *B*, should have 10 degrees draft. Lesser exterior draft, such as 3 and 5 degrees is frequently permissible, but always at some increased cost of forgings through more rapid failure of dies. See Table 3, Die-Draft Equivalents.

Ends of round sections are generally milled in the dies to create a spherical end crown known as "radial draft." Such 7-degree draft is depicted on drawings by swinging a radius equaling twice the barrel diameter, that is, a $\frac{7}{8}$ inch radius for $\frac{7}{16}$-inch diameter barrel; but it is never dimensioned, however, as at *C*. The same applies to half-rounds.

Fillets on forging drawing should be as large as possible, as at *D*, to assist the flow of hot metal and promote economical manufacture. Similarly projecting corners or edges should be nicely rounded since very sharp corners tend to propagate die checks or cracks and premature die failure. The usual broken corner on forgings is $\frac{1}{32}$ to $\frac{1}{16}$ inch radius. Draft angles are subject to increase as the dies wear. For this reason it is best to make new dies with as little draft as good practice permits.

Very narrow and deep depressions in the forging itself are weak male protrusions in the dies, which do not stand up under heat and pressure of hot metal during forging. They must be moderated in depth and carry 10 degrees draft as a minimum and good fillets. The depth of a depression or forged hole in either half-die should not exceed two-thirds of the least width of the depression.

Very thin ribs or webs on forgings should be avoided whenever possible, particularly on alloy-steel forgings. Thicknesses of $\frac{3}{32}$ to $\frac{1}{8}$ inch or greater are preferable for best production and lowest cost.

Accurately placed drill spots of 105 to 120 degrees included angle can be provided in the forging, as at *H*, on any surfaces approximately parallel to the forging plane to aid in drilling.

The forging operation produces a flash or surplus of thin waste all around the outline at the parting line, which is sheared or trimmed off close to the body by a hot or cold operation. A trimming flat, as at *K*, is left from $\frac{1}{32}$ to $\frac{1}{4}$ inch in width, depending on the size of the piece and the newness of the die. Unavoidable variations in trimming may cause a very slight bulge of flash to remain. Whenever portions of the trimmed outline must be held very close, the drawing should so specify.

Tolerances for Forgings

Standard tolerances for drop and upset forgings were adopted by the Drop Forging Association on Feb. 11, 1937. They are in two classes: regular and special. Regular tolerances are of two classes: commercial standard and close standard, the latter being used only where specified.

Regular tolerances apply to thickness; width, which includes shrinkage and die wear, mismatching, and trimmed size; draft angle; quantity; fillets, and corners. Thickness tolerance applies

TABLE 4.—THICKNESS TOLERANCES

Net Weights Up to—in Pounds	Commercial		Close	
	−	+	−	+
0.2	0.008	0.024	0.004	0.012
0.4	0.009	0.027	0.005	0.015
0.6	0.010	0.030	0.005	0.015
0.8	0.011	0.033	0.006	0.018
1.0	0.012	0.036	0.006	0.018
2.0	0.015	0.045	0.008	0.024
3.0	0.017	0.051	0.009	0.027
4.0	0.018	0.054	0.009	0.027
5.0	0.019	0.057	0.010	0.030
10.0	0.022	0.066	0.011	0.033
20.0	0.026	0.078	0.013	0.039
30.0	0.030	0.090	0.015	0.045
40.0	0.034	0.102	0.017	0.051
50.0	0.038	0.114	0.019	0.057
60.0	0.042	0.126	0.021	0.063
70.0	0.046	0.138	0.023	0.069
80.0	0.050	0.150	0.025	0.075
90.0	0.054	0.162	0.027	0.081
100.0	0.058	0.174	0.029	0.087

TABLE 5.—SHRINKAGE AND DIE WEAR

Lengths or Widths Up to	Shrinkage, Inches		Net Weight Up to	Die Wear in Pounds	
	Commercial + or −	Close + or −		Commercial + or −	Close + or −
1	0.003	0.002	1	0.032	0.016
2	0.006	0.003	3	0.035	0.018
3	0.009	0.005	5	0.038	0.019
4	0.012	0.006	7	0.041	0.021
5	0.015	0.008	9	0.044	0.022
6	0.018	0.009	11	0.047	0.024
Each additional inch add	0.003	0.0015	Each additional 2 pounds add.....	0.003	0.0015
For example:			**For example:**		
12	0.036	0.018	21	0.062	0.031
18	0.054	0.027	31	0.077	0.039
24	0.072	0.036	41	0.092	0.046
36	0.108	0.054	51	0.107	0.054
48	0.144	0.072	71	0.137	0.069
60	0.180	0.090	91	0.167	0.084

to over-all thickness, and in the case of drop forgings this is counted perpendicular to the parting plane of the die. On upset forgings they apply to the direction of ram travel, but only to such dimensions enclosed and formed by the die. Table 4 shows tolerances for thickness.

TABLE 6.—MISMATCHING TOLERANCE
(In Inches)

Net Weight in Pounds up to	Commercial	Close
1	0.015	0.010
7	0.018	0.012
13	0.021	0.014
19	0.024	0.016
Each additional 6 pounds add......	0.003	0.002
For example:		
37	0.033	0.022
55	0.042	0.028
79	0.054	0.036
97	0.063	0.042

Width and length tolerance are alike, their application being the same as for thickness, in both drop and upset forgings. Tables 5 and 6 show the tolerances for shrinkage and die wear and for mismatching. Shrinkage and die wear apply only to the part formed by a single die block. They are the sum of shrinkage and die-wear tolerances and are not used separately.

TABLE 7.—DRAFT-ANGLE TOLERANCES FOR DROP-HAMMER FORGINGS
(In Degrees)

	Nominal Angle	Commercial Limits	Close Limits
Outside............................	7	0 to 10	0 to 8
Inside holes and depressions.........	10	0 to 13	
	7	......	0 to 8

Mismatching applies to the errors due to misalignment of the dies. It does not include displacement caused by variations in the thickness of the forging. Mismatching tolerances are independent of, and in addition to, any other tolerance.

Trimmed-size tolerance must not be greater or less than the limiting sizes at the parting plane, imposed by the sum of the draft-angle tolerances and the shrinkage, and the die-wear tolerance.

Draft-angle tolerances are the permissible variations from the standard angle of draft. These are shown in Tables 7 and 8.

TABLE 8.—DRAFT-ANGLE TOLERANCES FOR UPSET FORGINGS
(In Degrees)

	Nominal Angle	Commercial Limits	Close Limits
Outside	3	0 to 5	0 to 4
Inside holes and depressions	5	0 to 8	0 to 7

Quantity tolerances are the permissible over- or underrun for each release or part shipment. Any shipment within these limits completes the order. This applies to both commercial and close tolerances. These tolerances are shown in Table 9.

TABLE 9.—QUANTITY TOLERANCES

Number of Pieces on Order	Overrun	Underrun
	Pieces	Pieces
1 to 2	1	0
3 to 5	2	1
6 to 19	3	1
20 to 29	4	2
30 to 39	5	2
40 to 49	6	3
50 to 59	7	3
60 to 69	8	4
70 to 79	9	4
80 to 99	10	5
	Per cent	Per cent
100 to 199	10	5.0
200 to 299	9	4.5
300 to 599	8	4.0
600 to 1,249	7	3.5
1,250 to 2,999	6	3.0
3,000 to 9,999	5	2.5
10,000 to 39,999	4	2.0
40,000 to 299,999	3	1.5
300,000 up	2	1.0

Fillet and corner tolerances apply to all meeting surfaces, even though drawings indicate sharp corners. If the drawings or models show larger fillets or corner dimensions than those shown in the table, these dimensions shall be followed and considered as special tolerances.

Fillet tolerances apply to inside corners and edges in which surfaces meet at an angle *less* than 180 degrees. Corner tolerances apply to outside corners and edges where the surfaces meet at an angle *greater* than 180 degrees. Where a corner tolerance applies on the meeting of two drafted surfaces, the tolerances apply to the narrow end of this meeting and the radius will increase toward the wide end. The total increase in the radius will equal the length of the drafted surface in inches, multiplied by the tangent of the nominal draft angle.

The radii of fillets and corners may be any value not greater than those given in Table 10.

TABLE 10.—FILLET AND CORNER TOLERANCES
(Radii in Inches)

Net Weight in Pounds up to	Commercial	Close
0.3	$\frac{3}{32}$	$\frac{3}{64}$
1.0	$\frac{1}{8}$	$\frac{1}{16}$
3.0	$\frac{5}{32}$	$\frac{5}{64}$
10.0	$\frac{3}{16}$	$\frac{3}{32}$
30.0	$\frac{7}{32}$	$\frac{7}{64}$
100.0	$\frac{1}{4}$	$\frac{1}{8}$

Drop-Forging Insert Dies[1]

To decrease costs, Westinghouse uses insert dies for such symmetrical forgings as lend themselves to this treatment, such as the pieces shown in Fig. 6. Inserts, as in Fig. 7, are used instead of making solid forging dies. Several sizes are made at once and kept in stock. The inserts are of chrome-vanadium steel with 45–55 point carbon. They are hardened to 42–47 Scleroscope before machining with carbide tools. Special tapered keys hold the

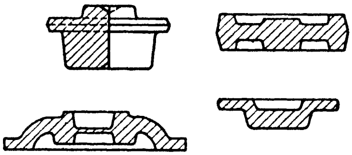

FIG. 6.—Forging Made with "Insert" Dies

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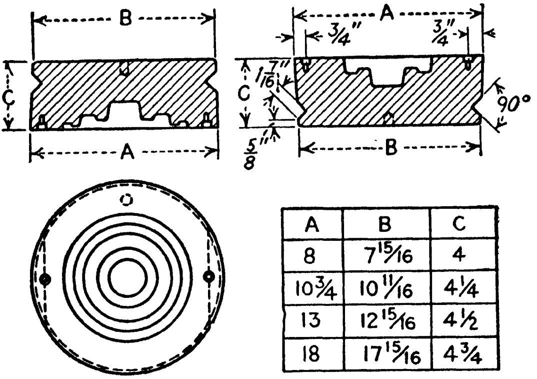
[1] J. H. Skerka.

inserts by the V groove around the insert. Two counterbored screw holes permit the use of eye bolts in removing the inserts from the master blocks. Some of the sizes are shown in Fig. 7. Savings up to 60 per cent have been made by using inserts.



A	B	C
8	7 15/16	4
10 3/4	10 11/16	4 1/4
13	12 15/16	4 1/2
18	17 15/16	4 3/4

FIG. 7.—How Die Inserts Are Made.

Forging Heats

W. E. Jominy of the General Motors Research Laboratories recommends the following as the maximum heats to be used in forging S.A.E. steels:

S.A.E.	Degrees Fahrenheit
1015	2400
1030	2350
1050	2300
1090	2150

Forging Machine Dies*

Rule I.—The limiting length of unsupported stock that can be gathered or upset in one blow without injurious buckling is three diameters.

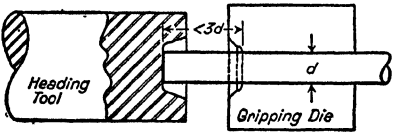


FIG. 8.

NOTE A: A safer maximum length is $2\frac{1}{2}d$; little attention need be paid to squareness of end if $l = 2d$. If $l > 3d$, buckling will occur

* Courtesy National Machinery Co.

near the middle of the unsupported length. These principles hold irrespective of whether the stock overhangs the face of the gripping dies, or whether any portion is gathered in either gripping dies, heading tool or both.

Rule II.—Lengths of stock more than $3d$ can be gathered or upset in one blow provided the upset is contained in either the gripping die or a straight or slightly tapered hole in the heading tool, and the diameter of the upset made in that blow is not more than $1\frac{1}{2}d$.

NOTE A: Multiple buckling will be checked by contact with sides of the die, and friction therewith will cause a fin to form around end of upset. Such long upsets cannot be made half in one die and half in the other, for central buckle will receive no side support.

NOTE B: A safer maximum is $1.3d$, and if Rule I is also applied, the upset will be free from end fins.

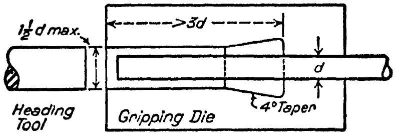


FIG. 9.

NOTE C: For very long upsets, it is helpful to have the end of the bar at a lower temperature, and to have a minimum diameter upset for the outer half of the die, the inner half tapering 4 degrees to wider diameter at the base.

NOTE D: In upsetting tubing, wall thickness cannot be increased externally more than 25 per cent at one blow; internal upsets are almost unlimited because arch effect prevents internal buckling.

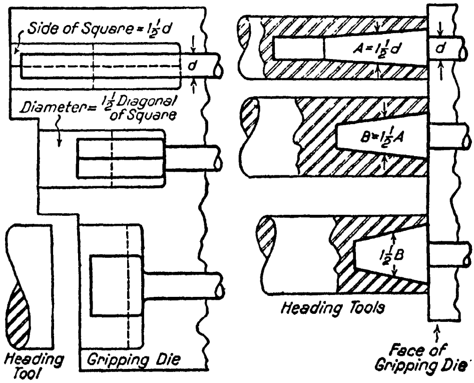


FIG. 10.

Rule III.—For upsets requiring more than $3d$ in length of stock, and in which the upset is $1\frac{1}{2}d$, the amount of unsupported stock beyond the face of the die must not exceed 1*d* (operation 1, at right).

NOTE A: Unsupported stock can amount to 1½*d* if diameter of upset is reduced to 1¼*d*.

Rule IV.—Large amounts of stock can be gathered by multiple application of Rule II and III, and by using square or tapered impressions.

NOTE A: In making the wide flange in sketch at left, below, the first and second impressions are within the 1½*d* limit, but the third, being a short upset under Rule I, is unlimited in diameter.

NOTE B: The side of the square may be 1½*d* of the original bar, and the diameter of the next round may be 1½ times the diagonal of the square.

NOTE C: Tapered holes are proportioned as to their diameters at midlength of unsupported stock.

Rule V.—Sliding dies, for upsetting stock at some distance from the end of a bar, are governed by all the above rules.

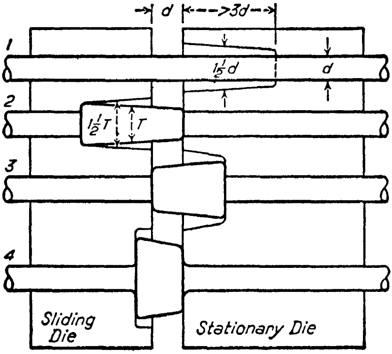


FIG. 11.

NOTE A: Friction along the sides of the sliding die will favor upsetting near its front end, so multiple impressions should be alternately in front and rear half, or alternately in sliding die and gripping die, as shown in lower part of sketch.

SECTION XXIII

KNOTS AND SLINGS

KNOTS AND SLINGS FOR HANDLING WORK

The knots described have been useful in work in out-of-the-way places; No. 1 indicates the meaning of the terms employed.

No. 2. Simple or Overhand Knot.—The simplest of all knots to tie, and may be used as a stop on a rope. A free end is necessary to make it. If strained, it injures the fiber of the rope more than a figure-8 knot, and it is difficult to unmake and liable to jam.

No. 3. Double Overhand Knot.—Used for the end of a rope when it is required to prevent its going through an eye, as in a pulley block or for the end of a halter rope. Also useful for shortening a rope and may be made with any number of turns: *A* in the illustration shows the first position; *B*, the knot finished with two turns; and *C*, one with four full turns of rope.

No. 4. Figure-8 Knot (Flemish).—May be employed as a stop on a rope; is less injurious to the fiber of the rope, and more easily undone than either the single or double overhand knot. If made with the rope doubled and the bight left long, it becomes a figure-8 hoop knot.

No. 5. Stevedore Knot.—End of the rope is wrapped twice around the standing and then passed through the eye. Useful as a stop on a rope to prevent the end going through an eye, as in a pulley block (see double overhand knot). Also employed instead of sewing the rope end with twine.

No. 6. Boat Knot (Marlinespike Hitch).—Suitable for quickly making a rope ladder, or getting a temporary pull on a rope with a marlinespike. No free ends required to form this knot. Point marked *A* must always be at the back of the spike or rung of the ladder, away from the direction of the weight or pull.

No. 7. Slip Knot (Simple Running Knot).—The simplest kind of slip knot. It may be used similarly to the packer's knot, but is not so good, as it is liable to pull through and does not bind on the rope.

No. 8. Tomfool Knot (Double Running Knot).—When the loops are drawn taut and the ends tied, this makes a pair of handcuffs which it is almost impossible for the person so secured to undo. It may be used as a barrel sling, half hitches being put on the ends, and the hook put under the knot itself. The bight marked 3 is passed through the overhand loop as shown by the dotted line.

No. 9. Flemish Loop.—This knot makes a simple loop for light work and may be used in the same way as a bowline, but is not so quickly made; neither is it so secure nor so easily undone. The security depends almost entirely upon the check knot.

No. 10. Bowline.—A generally useful knot when a loop of any sort that will not slip is required, as in a sling for lowering a man, or fastening a bucket to a rope.

No. 11. Bowline II.—A method of attaching the end of one rope to the standing of another. A half-turn is put in the standing and the end of the other rope taken through as if tying an ordinary bowline. This knot is practically a sheet bend.

No. 12. Running Bowline.—As shown in the first position, a half turn is made at *A* (shown dotted), and the end is passed through and to the back of the part marked *B*. This is a good slip knot and does not tighten on the standing, always remaining open.

No. 13. Bowline on a Bight.—The part *A* is passed behind *B* and then in the direction of the arrow to *C*. The bight *B* is then pulled taut. The two loops of this knot may be used as a man sling, a barrel sling, or as a double man harness, one loop under each shoulder. When tightened it will not slip.

In case of an injured man, one of the loops can be kept shorter than the other and adjusted under the armpits, the man being seated in the larger loop.

No. 14. Open-Hand Loop Knot and Figure-8 Loop Knot.—The upper loop knot is the one in common use and is adapted principally for small ropes. The lower, or figure-8 knot, is a better form and may be used on a larger rope as it injures the fiber less than the common form. These knots require a greater length of rope than the bowlines, but may be used in similar ways.

No. 15. Man-Harness Knot.—This knot can be tied in a rope with neither end free. The bight *A* is pulled through under *B* and over *C*, and the knot pulled taut. It is useful as allowing a number of men to get a good purchase on a rope for hauling; also to put loops in the rope to receive hooks at points other than the ends.

No. 16. Packer's Knot.—A modification of a simple slip knot, but has the advantage, when pulled tight, of biting on the standing at *A* and not easily slipping back. It is particularly useful for cording up rolls of camp bedding, etc. It can be made permanent by an added half hitch on the standing.

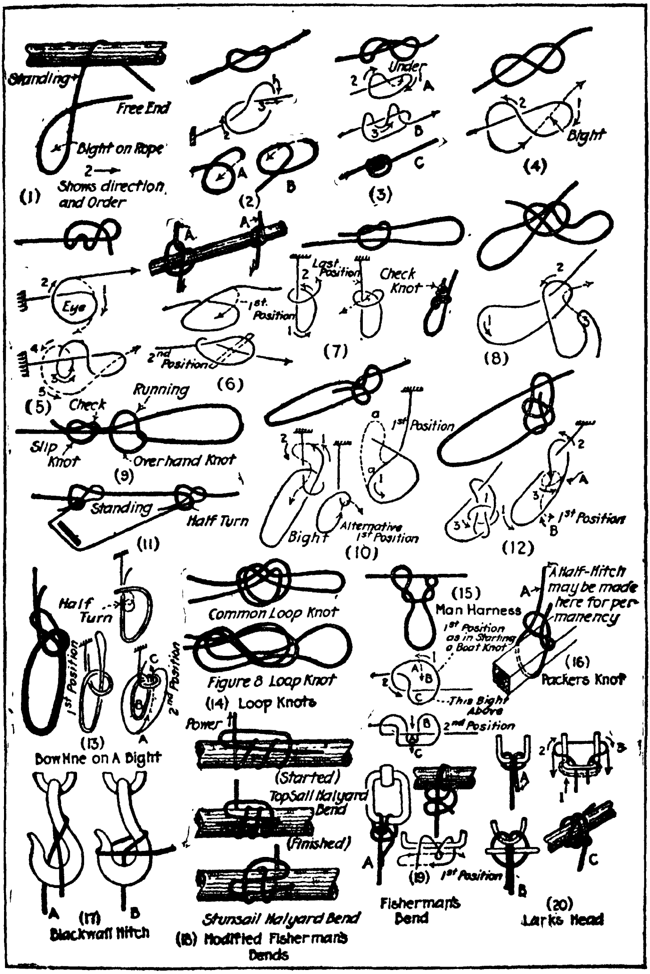
No. 17. Blackwall Hitch.—A convenient method for returning an empty rope on a hook. With a greasy rope, method *B* holds better.

No. 18. Modified Fisherman's Bends.—These are given as alternatives for securing ropes to poles or bars, and are adapted to heavy strains.

No. 19. Fisherman's Bend.—A better method than the gooseneck or lark's head (Fig. 20) for securing a rope to a chain or link. It is also used to fasten the rope to a bar or the bail of a bucket. Lashing at *A* is necessary to prevent pulling through. As shown in first position, two turns are taken over the link and the end brought back in front and passed through the turns as shown dotted.

No. 20. Lark's Head.—Useful for fastening a rope to the link of a chain or to a ring in a wall or box. It is not a secure knot unless lashed at *A*. *B* shows a toggle inserted to prevent slipping. *C* is a modified gooseneck on a bar, suitable for securing the end of a rope in scaffolding. The end must be placed at the back and the whole pulled taut.

No. 21. Half Hitch.—A quick and simple way of securing a rope to a timber when no great pull is expected. The rope end is placed under the pole, then back over to the right as shown. The end must always be placed right at the back away from the pull, as shown at *A*. The right-hand sketch shows the hitch with a slip to facilitate undoing.



No. 22. Timber Hitch.—This is the best and simplest of all timber hitches and may be used for towing or otherwise handling timber, rods, pipes, etc.; also for starting lashings on scaffolding or any kind of pole work. For raising or lowering timber, the half hitch should be placed high above the center of gravity to avoid slanting.

No. 23. Clove Hitch.—This is one of the most useful of all hitches, as it will take a strain in either direction without slackening. It is used for mooring ships, heads of derricks for guy lines, and all kinds of rigging work. It may be easily undone, or a bight may be put in instead of one end to use as a slip. When commencing to tie the hitch on a horizontal bar, the rule is over and back below, or the reverse of the procedure in tying a half hitch.

No. 24. Rolling Hitch.—This lashing is used for getting a grip on a large rope with a smaller one. Made in a chain, it can be applied to wire ropes and will not slip when the load has been taken up. It is also suitable for hauling on electric cables, or withdrawing diamond drill or other rods. For securing the end *A* may be brought down and be lashed to the large rope. In making, the end is passed over the spar twice, then returned back as shown at (3), then over behind as at (4), and up and under as at (5).

No. 25.—A square or reef knot, used only for joining two ropes together.

No. 26.—Sheet bend in an eye, generally used for an adjustable sling.

In supporting a swinging scaffold, it is often advantageous to use light material, while, at the same time, strength is required. A plank on edge is a great deal stiffer than the same plank laid flat, and **No. 27** shows how to sling a plank edgewise by a rope so that it will stay. The knot used is a very simple one. A clove hitch is made around the end of the plank; then one of the parts is twisted around the plank until the ends lead as shown in the sketch.

Very often it is desirable to shorten a piece of rope without cutting it. **No. 28** shows a sheep's shank which is used for this purpose. The rope is brought back on itself, making two or more bights, and a half hitch is taken around each bight. This knot will not slip and will nearly fall apart of its own accord if the strain is released, so that when this is liable to happen, it is well to pass a piece of wood through the loop *A* at each end and pull the rope tight on them.

One of the handiest knots to know is a bowline. The bowline will not slip, and is easy to untie. It can also be tied in the bight of a rope, and is then called a "bowline in a bight." The steps required to tie it are shown at **No. 29.** It is particularly handy when it is necessary to hitch an auxiliary tackle on a fall to get additional purchase for a heavy lift. This knot has all the good points of the simple bowline.

No. 30.—Clove or double half hitch.

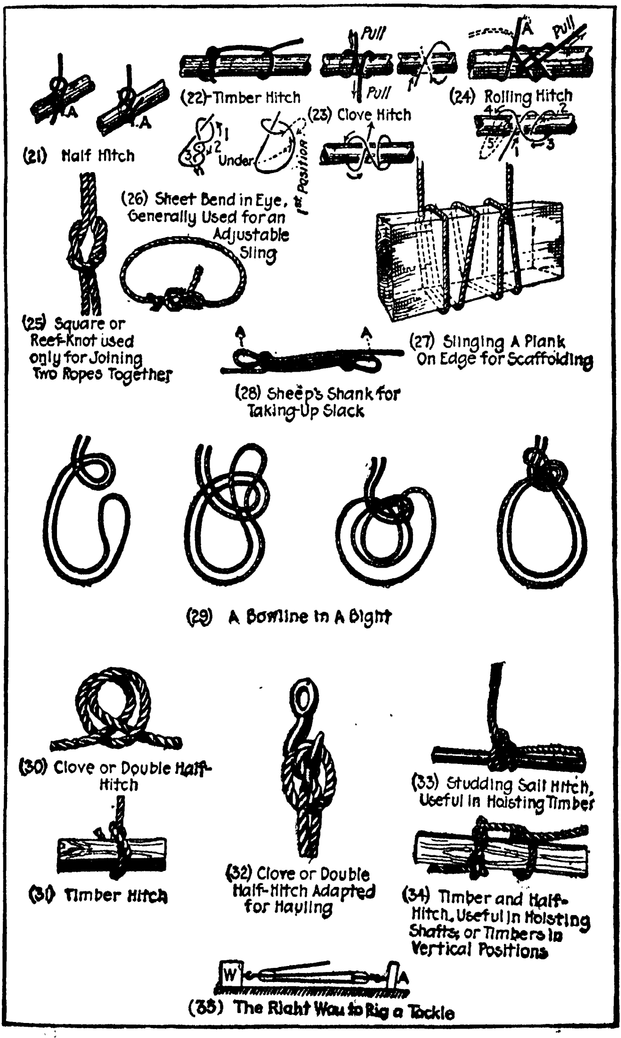
No. 31.—Timber hitch.

No. 32.—Clove or double half hitch as used for hauling.

No. 33.—Studding sail hitch as used in hoisting timber.

No. 34.—Timber and half hitch. Useful in hoisting shafting or timber in a vertical position.

In using a block and fall for pulling things, there is a right way and a wrong way of doing it. **No. 35** shows the right way, *W* being the weight to be moved. If *A* were the weight and *W* the post, the blocks being left as shown, then it would be wrong. The advantage of the right way of doing it is that the leverage due to one additional part of rope in the tackle is gained. Thus a three-part fall, rigged in



(21) Half Hitch

(22) Timber Hitch

(23) Clove Hitch

(24) Rolling Hitch

(25) Square or Reef-Knot used only for Joining Two Ropes Together

(26) Sheet Bend in Eye, Generally Used for an Adjustable Sling

(27) Slinging A Plank On Edge for Scaffolding

(28) Sheep's Shank for Taking-Up Slack

(29) A Bowline in A Bight

(30) Clove or Double Half-Hitch

(31) Timber Hitch

(32) Clove or Double Half-Hitch Adapted for Hauling

(33) Studding Sail Hitch, Useful in Hoisting Timber

(34) Timber and Half-Hitch, Useful in Hoisting Shafts, or Timbers in Vertical Positions

(35) The Right Way to Rig a Tackle

the right way, is as good as a four-part fall rigged in the wrong way, and has the additional advantage that there is one less sheave with its friction. In lifting a heavy weight, it is sometimes desirable to put a tackle on the fall to gain additional leverage; the common practice in a case of this kind is to hitch the auxiliary tackle to a "dead man." The right way is to hitch this tackle to the piece to be lifted alongside the main tackle, which adds considerably to the leverage, being equivalent to one more part to the main fall besides the gain by the use of the auxiliary fall.

SAFE LOADS FOR EYE-BOLTS AND FOR ROPES AND CHAINS

TABLE 1.—SAFE LOADS FOR EYE-BOLTS

	Threaded Diam.	Inside Diam. of Eye	Diam. Metal Around Eye	Safe Load, Lb.
Drop-forged steel	1/2	1 1/2	7/16	1,100
	9/16	1 9/16	17/32	1,500
	5/8	1 11/16	5/8	1,800
	3/4	1 13/16	3/4	2,800
	7/8	1 15/16	13/16	3,900
	1	2 1/16	15/16	5,100
	1 1/4	2 5/16	1 3/16	8,400
	1 1/2	2 9/16	1 3/8	12,200
	1 3/4	3 1/16	1 1/2	16,500
	2	3 1/16	1 5/8	21,800
D.B.G. iron E.L., 28,000 lb. per sq. in., welded	1 1/2	3	1 1/4	10,000
	1 3/4	4	1 1/2	11,000
	2	5	1 3/4	14,000
	2 1/4	6	2	16,000

TABLE 2.—SAFE LOADS ON ROPES AND CHAINS

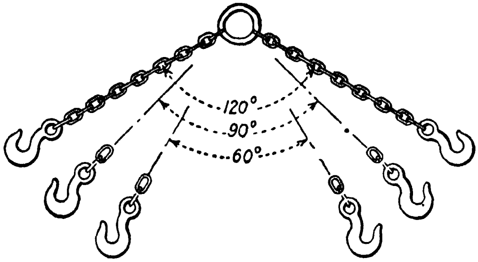
Manila Rope, Safe Load in Tons			
Diam. of Rope, In.	Single Rope	Two Part	Four Part
1/2	1/8	1/4	1/2
5/8	1/4	1/2	3/4
3/4	3/8	3/4	1 1/4
7/8	1/2	1	2
1	3/4	1 1/2	2 1/2
1 1/4	1	2	3
1 1/2	1 1/2	2 1/2	4
1 3/4	2	4	6
2	2 1/2	5	8
2 1/2	3 1/2	6 1/2	11
2 3/4	4 1/2	8	13

Wire Cable, Safe Load in Tons			
Diam. of Cable, In.	Single Rope	Two Part	Four Part
1/2	1	2	3 1/4
5/8	1 1/4	3 1/4	6 1/2
3/4	2 1/4	4 1/2	9
7/8	3 1/4	6	12
1	4	8	16
1 1/4	6	12	24
1 1/2	10	19	36
1 3/4	13	25	48
2	16	32	60

Chains, Safe Load in Tons			
Diam. of Chain, In.	Single Chain	Two Part	Four Part
1/4	1/2	3/4	1 1/2
3/8	1	1 1/2	3
1/2	2	3 1/2	6
5/8	3	5	9
3/4	5	9	15
7/8	6	10 1/2	18
1	8	14	24
1 1/8	11	19	33
1 1/4	13	23	39
1 1/2	18	32	54

Safe Loads in Pounds for Double-Chain Slings

When lifting with a double sling the load varies with the angle as shown in the table which gives the safe load of chain at the various angles shown. At an angle of 120 degrees the load is doubled. Never tie knots in chains, take up slack with adjusters or wedges.



Size of Chain	Maximum	60°	90°	120°
¼ inch	2000	1720	1400	1000
5/16 "	2930	2500	2040	1460
⅜ "	4260	3660	2980	2130
7/16 "	6000	5100	4200	3000
½ "	8000	6880	5000	4000
⅝ "	12320	10600	8620	6160

PROOF AND BREAK TEST LOADS

Proof Test Loads in Pounds, for Wrought-Iron Crane Chain, Recommended by the Association of American Railroads

NOMINAL SIZE OF CHAIN BAR, IN INCHES	PROOF TEST LOADS, IN POUNDS, CRANE CHAIN WROUGHT IRON
¼	1,345
5/16	2,100
⅜	3,020
7/16	4,115
½	5,375
9/16	6,800
⅝	8,395
¾	12,080
⅞	16,430
1	21,490
1⅛	25,380
1¼	31,350
1⅜	37,920
1½	45,100
1⅝	53,000
1¾	61,400
1⅞	70,500
2	80,200

SECTION XXIV
GENERAL REFERENCE TABLES

Common Weights and Measures

LINEAR OR MEASURE OF LENGTH

12 inches = 1 foot. 3 feet = 1 yard.
5½ yards 1 rod. 40 rods = furlong.
8 furlongs = 1 mile.

EQUIVALENT MEASURES

Inches	Feet	Yards	Rods	Furlongs	Mile
36	3	1			
198	16.5	5.5	1		
7,920	660	220	40	1	
63,360	5,280	1,760	320	8	1

SQUARE MEASURE

144 square inches = 1 square foot
9 square feet = 1 square yard
30¼ square yards = 1 square rod
160 square rods = 1 acre
640 acres = 1 square mile
1 acre = 43,560 square feet = 208.7 feet on side
10 acres = a square 660 feet on each side.

EQUIVALENT MEASURE

Sq. Mi.	A.	Sq. Rd.	Sq. Yd.	Sq. Ft.	Sq. In.
1	640	102,400	3,097,600	27,878,400	4,014,489,600
	1	160	4840	43,560	6,272,640

CUBIC MEASURE

1728 cubic inches = 1 cubic foot. 128 cubic feet = 1 cord.
27 cubic feet = 1 cubic yard. 24¾ cubic feet = 1 perch.
1 cu. yd. = 27 cu. ft. = 46,656 cu. in.

WEIGHT—AVOIRDUPOIS

437.5 grains = 1 ounce. 100 pounds = 1 hundredweight.
16 ounces = 1 pound. 2000 pounds = 1 ton.
2240 pounds = 1 long ton.
1 ton = 20 cwt. = 2000 lbs. = 32,000 oz. = 14,000,000 gr

WEIGHT = TROY

24 grains = 1 pennyweight. 20 dwt. = 1 ounce.
12 ounces = 1 pound.
1 lb. = 12 oz. = 240 dwt. = 5760 gr.

DRY MEASURE

2 pints = 1 quart. 8 quarts = 1 peck.
4 pecks = 1 bushel
1 bu. = 4 pk. = 32 qt. = 64 pt.
U. S. bushel = 2150.42 cu. in. British = 2218.19 cu. in.

LIQUID MEASURE

4 gills = 1 pint. 4 quarts = 1 gallon.
2 pints = 1 quart. 31½ gallons = 1 barrel.
2 barrels or 63 gals. = 1 hogshead.
1 hhd. = 2 bbl. = 63 gals. = 252 qt. = 504 pt. = 2016 gi.

The U. S. gallon contains 231 cu. in. = .134 cu. ft.
One cubic foot = 7.481 gallons.
One cubic foot weighs 62.425 lbs. at 39.2 deg. Fahr.
One gallon weighs 8.345 lbs. British Imperial gallon weighs 10 lb.
For rough calculations 1 cu. ft. is called 7¼ gallons and 1 gallon as 8⅓ lbs.

ANGLES OR ARCS

60 seconds = 1 minute. 90 degrees = 1 rt. angle or quadrant.
60 minutes = 1 degree. 360 degrees = 1 circle.
1 circle = 360° = 21,600′ = 1,296,000″.
1 minute of arc on the earth's surface is 1 nautical mile = 1.15 times a land mile or 6080 feet.

WEIGHT OF A CUBIC FOOT OF SUBSTANCES

NAMES OF SUBSTANCES	Average Weight, Lbs.
Anthracite, broken, loose	54
Ash, American white, dry	38
Brick, best pressed	150
" common hard	125
Brickwork, pressed brick	140
" ordinary	112
Cement, hydraulic, ground, loose, American, Rosendale	94
" " " " English, Portland	90
Cherry, dry	42
Chestnut, dry	41
Coal, bituminous broken, loose	49
Coke, loose, of good coal	27
Ebony, dry	76
Elm, dry	35

WEIGHT OF A CUBIC FOOT OF SUBSTANCES—*Continued*

NAMES OF SUBSTANCES	Average Weight, Lbs.
Glass, common window	157
Granite	170
Gravel, about the same as sand	
Hemlock, dry	25
Hickory, dry	53
Ice	58.7
Lignum Vitæ, dry	83
Lime, quick, ground, loose, or in small lumps	53
Limestones and Marbles	168
Mahogany, Spanish, dry	53
Maple, dry	49
Marbles, see Limestones.	
Masonry, of granite or limestone, well dressed	165
Mercury, at 32° Fahrenheit	849
Mica	183
Oak, white, dry	52
" other kinds ... 32 to	45
Petroleum	55
Pine, white, dry	25
" yellow, Northern	34
" " Southern	45
Rosin	69
Salt, coarse, Syracuse, N. Y	45
Sand, of pure quartz, dry, loose ... 90 to	106
Sandstones, fit for building	151
Slate	175
Spruce, dry	25
Sulphur	125
Sycamore, dry	37
Walnut, black, dry	38
Water, pure rain or distilled, at 60° Fahrenheit	62.48
" sea	64
Wax, bees	60.5

Green timbers usually weigh from one-fifth to one-half more than dry.

For weight of metals see page 1073.

THE METRIC SYSTEM

The metric system is based on the meter which was designed to be one ten-millionth (1/10,000,000) part of the earth's meridian quadrant, through Dunkirk and Formentera. Later investigations, however, have shown that the Meter exceeds one ten-millionth part by almost one part in 6,400. The value of the meter, as authorized by the United States Government, is 39.37 inches. The metric system was legalized by the United States Government in 1866.

The three principal units are the meter, the unit of length, the liter, the unit of capacity, and the gram, the unit of weight. Multiples of these are obtained by prefixing the Greek words: deka (10), hekto (100), and kilo (1,000). Divisions are obtained by prefixing the Latin words: deci ($\frac{1}{10}$), centi ($\frac{1}{100}$), and milli (1/1,000). Abbreviations of the multiples begin with a capital letter, and of the divisions with a small letter, as in the following tables:

MEASURES OF LENGTH

10 millimeters (mm) .... = 1 centimeter .... cm.
10 centimeters .... = 1 decimeter .... dm.
10 decimeters .... = 1 meter .... m.
10 meters .... = 1 dekameter .... Dm.
10 dekameters .... = 1 hektometer .... Hm.
10 hektometers .... = 1 kilometer .... Km.

MEASURES OF SURFACE (NOT LAND)

100 square millimeters (mm^2) .... = 1 square centimeter .... cm^2.
100 square centimeters .... = 1 square decimeter .... dm^2.
100 square decimeters .... = 1 square meter .... m^2.

MEASURES OF VOLUME

1000 cubic millimeters (mm^3) .... = 1 cubic centimeter .... cm^3.
1000 cubic centimeters .... = 1 cubic decimeter .... dm^3.
1000 cubic decimeters .... = 1 cubic meter .... m^3.

MEASURES OF CAPACITY

10 milliliters (ml) .... = 1 centiliter .... cl.
10 centiliters .... = 1 deciliter .... dl.
10 deciliters .... = 1 liter .... l.
10 liters .... = 1 dekaliter .... Dl.
10 dekaliters .... = 1 hektoliter .... Hl.
10 hektoliters .... = 1 kiloliter .... Kl.

NOTE. — The liter is equal to the volume occupied by 1 cubic decimeter.

MEASURES OF WEIGHT

10 milligrams (mg) .... = 1 centigram .... cg.
10 centigrams .... = 1 decigram .... dg.
10 decigrams .... = 1 gram .... g.
10 grams .... = 1 dekagram .... Dg.
10 dekagrams .... = 1 hektogram .... Hg.
10 hektograms .... = 1 kilogram .... Kg.
1000 kilograms .... = 1 ton .... T.

NOTE.—The gram is the weight of 1 cubic centimeter of pure distilled water at a temperature of 39.2°F., the kilogram is the weight of 1 liter of water; the ton is the weight of 1 cubic meter of water.

Metric and English Conversion Table

MEASURES OF LENGTH

1 meter = 39.37 inches.
3.28083 feet.
1.0936 yds.
1 centimeter = .3937 inch.
1 millimeter = .03937 inch, or
$\frac{1}{25}$ inch nearly.
1 kilometer = 0.62137 mile.

1 foot = .3048 meter.
1 inch = 2.54 centimeters.
25.4 millimeters.

MEASURES OF SURFACE

1 square meter = 10.764 square feet.
1.196 square yds.
1 square centimeter = .155 sq. in.
1 square millimeter = .00155 sq. in.

1 square yard = .836 square meter.
1 square foot = .0929 square meter.
1 square in. = 6.452 sq. centimeters:
645.2 sq. millimeters.

MEASURES OF VOLUME AND CAPACITY

1 cubic meter = 35.314 cubic feet.
1.308 cubic yards.
264.2 gallons (231 cubic inch).
1 cubic decimeter = 61.023 cubic in.
.0353 cubic ft.
1 cubic centimeter = .061 cubic inch.
1 liter = 1 cubic decimeter.
61.023 cubic inches.
.0353 cubic foot.
1.0567 quarts (U. S.)
.2642 gallons (U. S.)
2.202 lbs. of water at 62° F.

1 cubic yard = .7645 cubic meter.
1 cubic ft. = .02832 cubic meter.
28.317 cubic decimeters.
28.317 liters.
1 cubic inch = 16.387 cubic centimeters.
1 gallon (British) = 4.543 liters.
1 gallon (U. S.) = 3.785 liters.

MEASURES OF WEIGHT

1 gram = 15.432 grains.
1 kilogram = 2.2046 pounds.
1 metric ton = .9842 ton of 2240 lbs.
19.68 cwts.
2204.6 lbs.

1 grain = .0648 grams.
1 ounce avoirdupois = 28.35 grams.
1 pound = .4536 kilograms.
1 ton of 2240 lbs. = 1.016 metric tons.
1016 kilograms.

MISCELLANEOUS CONVERSION FACTORS

1 kilogram per meter = .6720 pound per foot.
1 gram per square millimeter = 1.422 pounds per square inch.
1 kilogram per square meter = 0.2048 pound per square foot.
1 kilogram per cubic meter = .0624 pound per cubic foot.
1 pound per foot = 1.488 kilograms per meter.
1 pound per square foot = 4.882 kilograms per square meter.
1 pound per cubic foot = 16.02 kilograms per cubic meter.
1 Calorie (French Thermal Unit) = 3.968 B. T. U. (British Thermal Unit).
1 Horse-power = 33,000 foot-pounds per minute.
746 Watts.
1 Watt (Unit of Electrical Power) = .00134 Horse-power.
44.24 foot-pounds per minute
1 Kilowatt = 1000 Watts.
1.34 Horse-power.
44240 foot-pounds per minute.

Inches and Millimeters

The following tables are calculated on the newly adopted relation of 25.4 millimeters to the American inch. This replaces the old ratio of 25.40005:1, a difference of two parts in a million. This ratio was approved at a meeting of American Standards Association on October 21, 1932.

The adoption of the new ratio simplifies calculations and eliminates errors caused by various interpretations of the decimal to be used. The following tables are from the Bureau of Standards.

INCHES TO MILLIMETERS
Basis: 1 Inch = 25.4 Millimeters

Inches	Millimeters	Inches	Millimeters	Inches	Millimeters	Inches	Millimeters
1	25.4	26	660.4	51	1295.4	76	1930.4
2	50.8	27	685.8	52	1320.8	77	1955.8
3	76.2	28	711.2	53	1346.2	78	1981.2
4	101.6	29	736.6	54	1371.6	79	2006.6
5	127.0	30	762.0	55	1397.0	80	2032.0
6	152.4	31	787.4	56	1422.4	81	2057.4
7	177.8	32	812.8	57	1447.8	82	2082.8
8	203.2	33	838.2	58	1473.2	83	2108.2
9	228.6	34	863.6	59	1498.6	84	2133.6
10	254.0	35	889.0	60	1524.0	85	2159.0
11	279.4	36	914.4	61	1549.4	86	2184.4
12	304.8	37	939.8	62	1574 8	87	2209.8
13	330.2	38	965.2	63	1600.2	88	2235.2
14	355.6	39	990.6	64	1625.6	89	2260.6
15	381.0	40	1016.0	65	1651.0	90	2286.0
16	406.4	41	1041.4	66	1676.4	91	2311.4
17	431.8	42	1066.8	67	1701.8	92	2336.8
18	457.2	43	1092.2	68	1727.2	93	2362.2
19	482.6	44	1117.6	69	1752.6	94	2387.6
20	508.0	45	1143.0	70	1778.0	95	2413.0
21	533.4	46	1168.4	71	1803.4	96	2438.4
22	558.8	47	1193.8	72	1828.8	97	2463.8
23	584.2	48	1219.2	73	1854.2	98	2489.2
24	609.6	49	1244.6	74	1879.6	99	2514.6
25	635.0	50	1270.0	75	1905.0	100	2540.0

NOTE.—The above table is exact.

MILLIMETERS TO INCHES
Basis: 1 Inch = 25.4 Millimeters

Millimeters	Inches	Millimeters	Inches	Millimeters	Inches	Millimeters	Inches
1	0.039370	26	1.023622	51	2.007874	76	2.992126
2	0.078740	27	1.062992	52	2.047244	77	3.031496
3	0.118110	28	1.102362	53	2.086614	78	3.070866
4	0.157480	29	1.141732	54	2.125984	79	3.110236
5	0.196850	30	1.181102	55	2.165354	80	3.149606
6	0.236220	31	1.220472	56	2.204724	81	3.188976
7	0.275591	32	1.259843	57	2.244094	82	3.228346
8	0.314961	33	1.299213	58	2.283465	83	3.267717
9	0.354331	34	1.338583	59	2.322835	84	3.307087
10	0.393701	35	1.377953	60	2.362205	85	3.346457
11	0.433071	36	1.417323	61	2.401575	86	3.385827
12	0.472441	37	1.456693	62	2.440945	87	3.425197
13	0.511811	38	1.496063	63	2.480315	88	3.464567
14	0.551181	39	1.535433	64	2.519685	89	3.503937
15	0.590551	40	1.574803	65	2.559055	90	3.543307
16	0.629921	41	1.614173	66	2.598425	91	3.582677
17	0.669291	42	1.653543	67	2.637795	92	3.622047
18	0.708661	43	1.692913	68	2.677165	93	3.661417
19	0.748031	44	1.732283	69	2.716535	94	3.700787
20	0.787402	45	1.771654	70	2.755906	95	3.740157
21	0.826772	46	1.811024	71	2.795276	96	3.779528
22	0.866142	47	1.850394	72	2.834646	97	3.818898
23	0.905512	48	1.889764	73	2.874016	98	3.858268
24	0.944882	49	1.929134	74	2.913386	99	3.897638
25	0.984252	50	1.968504	75	2.952756	100	3.937008

NOTE.—The above table is approximate: 1/25.4 = 0.039370078740+.

Common Fractions of an Inch to Millimeters
Basis: 1 Inch = 25.4 Millimeters

Seconds	Fourths	Eighths	Sixteenths	Thirty-seconds	Sixty-fourths	Decimal Inch	Millimeters
					1	0.015625	0.396875
				1		0.031250	0.793750
					3	0.046875	1.190625
			1			0.062500	1.587500
					5	0.078125	1.984375
				3		0.093750	2.381250
					7	0.109375	2.778125
		1				0.125000	3.175000
					9	0.140625	3.571875
				5		0.156250	3.968750
					11	0.171875	4.365625
			3			0.187500	4.762500
					13	0.203125	5.159375
				7		0.218750	5.556250
					15	0.234375	5.953125
	1					0.250000	6.350000
					17	0.265625	6.746875
				9		0.281250	7.143750
					19	0.296875	7.540625
			5			0.312500	7.937500
					21	0.328125	8.334375
				11		0.343750	8.731250
					23	0.359375	9.128125
		3				0.375000	9.525000
					25	0.390625	9.921875
				13		0.406250	10.318750
					27	0.421875	10.715625
			7			0.437500	11.112500
					29	0.453125	11.509375
				15		0.468750	11.906250
					31	0.484375	12.303125
1						0.500000	12.700000
					33	0.515625	13.096875
				17		0.531250	13.493750
					35	0.546875	13.890625
			9			0.562500	14.287500
					37	0.578125	14.684375
				19		0.593750	15.081250
					39	0.609375	15.478125
		5				0.625000	15.875000
					41	0.640625	16.271875
				21		0.656250	16.668750
					43	0.671875	17.065625
			11			0.687500	17.462500
					45	0.703125	17.859375
				23		0.718750	18.256250
					47	0.734375	18.653125
	3					0.750000	19.050000
					49	0.765625	19.446875
				25		0.781250	19.843750

Common Fractions of an Inch to Millimeters.—*Continued*

Seconds	Fourths	Eighths	Sixteenths	Thirty-seconds	Sixty-fourths	Decimal Inch	Millimeters
					51	0.796875	20.240625
			13			0.812500	20.637500
					53	0.828125	21.034375
				27		0.843750	21.431250
					55	0.859375	21.828125
		7				0.875000	22.225000
					57	0.890625	22.621875
				29		0.906250	23.018750
					59	0.921875	23.415625
			15			0.937500	23.812500
					61	0.953125	24 209376
				31		0.968750	24.606250
					63	0.984375	25 003125
2	4	8	16	32	64	1.000000	25.400000

Note.—The above table is exact; all figures beyond the six places given are zeros.

Equivalents of Compound Units

Symbols	Metric Units	American Equivalents
gr./cm.	Gram per centimeter	0.0055 pound per inch
kg./m.	Kilogram per meter	0.055 pound per inch
kg./km.	Kilogram per kilometer	3.54 pounds per mile
kg./qcm.	Kilogram per square centimeter	14.22 pounds per square inch
kg./ha.	Kilogram per hectar	0.89 pound per acre
t./m.^{2}	Metric ton per square meter	0.102 short ton per square foot
kg./m.^{3}	Kilogram per cubic meter	0.062 pound per cubic foot
kg./hl.	Kilogram per hectoliter	0.083 pounds per gallon
t./m.^{3}	Metric ton per cubic meter	62.4 pounds per cubic foot
kg./h.-p.	Kilogram per Continental horsepower	2.23 pounds per American h.-p.
kg./t.	Kilogram per metric ton	2 pounds per short ton
kgm./kg.	Kilogram-meter per kilogram	3.28 foot-pounds per pound
kgm./qcm.	Kilogram-meter per square centimeter	46.58 foot-pounds per square inch
t./km.	Metric ton per kilometer	1.77 short tons per mile
t.-km.	Metric ton-kilometer	0.6849 short ton-mile

DECIMAL EQUIVALENTS OF FRACTIONS OF MILLIMETERS.
(ADVANCING BY $\frac{1}{100}$ MM.)

mm.	Inches	mm.	Inches	mm.	Inches	mm.	Inches
$\frac{1}{100}$	= .00039	$\frac{26}{100}$	= .01024	$\frac{51}{100}$	= .02008	$\frac{76}{100}$	= .02992
$\frac{2}{100}$	= .00079	$\frac{27}{100}$	= .01063	$\frac{52}{100}$	= .02047	$\frac{77}{100}$	= .03032
$\frac{3}{100}$	= .00118	$\frac{28}{100}$	= .01102	$\frac{53}{100}$	= .02087	$\frac{78}{100}$	= .03071
$\frac{4}{100}$	= .00157	$\frac{29}{100}$	= .01142	$\frac{54}{100}$	= .02126	$\frac{79}{100}$	= .03110
$\frac{5}{100}$	= .00197	$\frac{30}{100}$	= .01181	$\frac{55}{100}$	= .02165	$\frac{80}{100}$	= .03150
$\frac{6}{100}$	= .00236	$\frac{31}{100}$	= .01220	$\frac{56}{100}$	= .02205	$\frac{81}{100}$	= .03189
$\frac{7}{100}$	= .00276	$\frac{32}{100}$	= .01260	$\frac{57}{100}$	= .02244	$\frac{82}{100}$	= .03228
$\frac{8}{100}$	= .00315	$\frac{33}{100}$	= .01299	$\frac{58}{100}$	= .02283	$\frac{83}{100}$	= .03268
$\frac{9}{100}$	= .00354	$\frac{34}{100}$	= .01339	$\frac{59}{100}$	= .02323	$\frac{84}{100}$	= .03307
$\frac{10}{100}$	= .00394	$\frac{35}{100}$	= .01378	$\frac{60}{100}$	= .02362	$\frac{85}{100}$	= .03346
$\frac{11}{100}$	= .00433	$\frac{36}{100}$	= .01417	$\frac{61}{100}$	= .02402	$\frac{86}{100}$	= .03386
$\frac{12}{100}$	= .00472	$\frac{37}{100}$	= .01457	$\frac{62}{100}$	= .02441	$\frac{87}{100}$	= .03425
$\frac{13}{100}$	= .00512	$\frac{38}{100}$	= .01496	$\frac{63}{100}$	= .02480	$\frac{88}{100}$	= .03465
$\frac{14}{100}$	= .00551	$\frac{39}{100}$	= .01535	$\frac{64}{100}$	= .02520	$\frac{89}{100}$	= .03504
$\frac{15}{100}$	= .00591	$\frac{40}{100}$	= .01575	$\frac{65}{100}$	= .02559	$\frac{90}{100}$	= .03543
$\frac{16}{100}$	= .00630	$\frac{41}{100}$	= .01614	$\frac{66}{100}$	= .02598	$\frac{91}{100}$	= .03583
$\frac{17}{100}$	= .00669	$\frac{42}{100}$	= .01654	$\frac{67}{100}$	= .02638	$\frac{92}{100}$	= .03622
$\frac{18}{100}$	= .00709	$\frac{43}{100}$	= .01693	$\frac{68}{100}$	= .02677	$\frac{93}{100}$	= .03661
$\frac{19}{100}$	= .00748	$\frac{44}{100}$	= .01732	$\frac{69}{100}$	= .02717	$\frac{94}{100}$	= .03701
$\frac{20}{100}$	= .00787	$\frac{45}{100}$	= .01772	$\frac{70}{100}$	= .02756	$\frac{95}{100}$	= .03740
$\frac{21}{100}$	= .00827	$\frac{46}{100}$	= .01811	$\frac{71}{100}$	= .02795	$\frac{96}{100}$	= .03780
$\frac{22}{100}$	= .00866	$\frac{47}{100}$	= .01850	$\frac{72}{100}$	= .02835	$\frac{97}{100}$	= .03819
$\frac{23}{100}$	= .00906	$\frac{48}{100}$	= .01890	$\frac{73}{100}$	= .02874	$\frac{98}{100}$	= .03858
$\frac{24}{100}$	= .00945	$\frac{49}{100}$	= .01929	$\frac{74}{100}$	= .02913	$\frac{99}{100}$	= .03898
$\frac{25}{100}$	= .00984	$\frac{50}{100}$	= .01969	$\frac{75}{100}$	= .02953	1	= .03937

Metric Equivalents

1. To find the metric equivalent of any number of thousandths of an inch:

Multiply 0.0254 by the number of thousandths.

2. To find the metric equivalent of any number of ten thousandths of an inch:

Multiply 0.00254 by the number of thousandths.

The answer is in millimeters.
The metric equivalent of 0.045 inch would be 0.0254 × 0.045 or 0.0011430 millimeters.

DECIMAL EQUIVALENTS OF MILLIMETERS AND FRACTIONS OF MILLIMETERS. (ADVANCING BY $\frac{1}{50}$ MM. AND 1 MM.)

mm.	Inches	mm.	Inches	mm.	Inches	mm.	Inches
		$\frac{40}{50}$	.03150	31	1.22047	71	2.79527
$\frac{1}{50}$	.00079	$\frac{41}{50}$	.03228	32	1.25984	72	2.83464
$\frac{2}{50}$	.00157	$\frac{42}{50}$	.03307	33	1.29921	73	2.87401
$\frac{3}{50}$	.00236	$\frac{43}{50}$	.03386	34	1.33858	74	2.91338
$\frac{4}{50}$	.00315	$\frac{44}{50}$	.03465	35	1.37795	75	2.95275
$\frac{5}{50}$	.00394	$\frac{45}{50}$	.03543	36	1.41732	76	2.99212
$\frac{6}{50}$	.00472	$\frac{46}{50}$	.03622	37	1.45669	77	3.03149
$\frac{7}{50}$	.00551	$\frac{47}{50}$	.03701	38	1.49606	78	3.07086
$\frac{8}{50}$	.00630	$\frac{48}{50}$	.03780	39	1.53543	79	3.11023
$\frac{9}{50}$	.00709	$\frac{49}{50}$	.03858	40	1.57480	80	3.14960
$\frac{10}{50}$	.00787	1	.03937	41	1.61417	81	3.18897
$\frac{11}{50}$	.00866	2	.07874	42	1.65354	82	3.22834
$\frac{12}{50}$	.00945	3	.11811	43	1.69291	83	3.26771
$\frac{13}{50}$	.01024	4	.15748	44	1.73228	84	3.30708
$\frac{14}{50}$	.01102	5	.19685	45	1.77165	85	3.34645
$\frac{15}{50}$	.01181	6	.23622	46	1.81102	86	3.38582
$\frac{16}{50}$	.01260	7	.27559	47	1.85039	87	3.42519
$\frac{17}{50}$	.01339	8	.31496	48	1.88976	88	3.46456
$\frac{18}{50}$	.01417	9	.35433	49	1.92913	89	3.50393
$\frac{19}{50}$	.01496	10	.39370	50	1.96850	90	3.54330
$\frac{20}{50}$	.01575	11	.43307	51	2.00787	91	3.58267
$\frac{21}{50}$	.01654	12	.47244	52	2.04724	92	3.62204
$\frac{22}{50}$	.01732	13	.51181	53	2.08661	93	3.66141
$\frac{23}{50}$	.01811	14	.55118	54	2.12598	94	3.70078
$\frac{24}{50}$	.01890	15	.59055	55	2.16535	95	3.74015
$\frac{25}{50}$	.01969	16	.62992	56	2.20472	96	3.77952
$\frac{26}{50}$	.02047	17	.66929	57	2.24409	97	3.81889
$\frac{27}{50}$	.02126	18	.70866	58	2.28346	98	3.85826
$\frac{28}{50}$	.02205	19	.74803	59	2.32283	99	3.89763
$\frac{29}{50}$	.02283	20	.78740	60	2.36220	100	3.93700
$\frac{30}{50}$	.02362	21	.82677	61	2.40157		
$\frac{31}{50}$	.02441	22	.86614	62	2.44094		
$\frac{32}{50}$	.02520	23	.90551	63	2.48031		
$\frac{33}{50}$	.02598	24	.94488	64	2.51968		
$\frac{34}{50}$	.02677	25	.98425	65	2.55905		
$\frac{35}{50}$	.02756	26	1.02362	66	2.59842		
$\frac{36}{50}$	.02835	27	1.06299	67	2.63779		
$\frac{37}{50}$	.02913	28	1.10236	68	2.67716		
$\frac{38}{50}$	.02992	29	1.14173	69	2.71653		
$\frac{39}{50}$	.03071	30	1.18110	70	2.75590		

1 mm. = 0.03937 in.
1 cm. = 0.3937 "
1 dm. = 3.937 "
1 m. = 39.37 "

Fractions, Decimals and Millimeters

This will be found useful in comparing the millimeter with both the decimal and common fractions of an inch.

FRACTIONS AND DECIMALS OF INCH WITH MILLIMETER EQUIVALENT

Fraction of Inch	Decimal of Inch	Milli-meters	Fraction of Inch	Decimal of Inch	Milli-meters
1/64	0.015625	0.3968	33/64	0.515625	13.0966
1/32	0.03125	0.7937	17/32	0.53125	13.4934
3/64	0.046875	1.1906	35/64	0.546875	13.8903
1/16	0.0625	1.5875	9/16	0.5625	14.2872
5/64	0.078125	1.9843	37/64	0.578125	14.6841
3/32	0.09375	2.3812	19/32	0.59375	15.0809
7/64	0.109375	2.7780	39/64	0.609375	15.4778
1/8	0.125	3.1749	5/8	0.625	15.8747
9/64	0.140625	3.5718	41/64	0.640625	16.2715
5/32	0.15625	3.9686	21/32	0.65625	16.6684
11/64	0.171875	4.3655	43/64	0.671875	17.0653
3/16	0.1875	4.7624	11/16	0.6875	17.4621
13/64	0.203125	5.1592	45/64	0.703125	17.8590
7/32	0.21875	5.5561	23/32	0.71875	18.2559
15/64	0.234375	5.9530	47/64	0.734375	18.6527
1/4	0.25	6.3498	3/4	0.75	19.0496
17/64	0.265625	6.7467	49/64	0.765625	19.4465
9/32	0.28125	7.1436	25/32	0.78125	19.8433
19/64	0.296875	7.5404	51/64	0.796875	20.2402
5/16	0.3125	7.9373	13/16	0.8125	20.6371
21/64	0.328125	8.3342	53/64	0.828125	21.0339
11/32	0.34375	8.7310	27/32	0.843750	21.4308
23/64	0.359375	9.1279	55/64	0.859375	21.8277
3/8	0.375	9.5248	7/8	0.875	22.2245
25/64	0.390625	9.9216	57/64	0.890625	22.6214
13/32	0.40625	10.3185	29/32	0.90625	23.0183
27/64	0.421875	10.7154	59/64	0.921875	23.4151
7/16	0.4375	11.1122	15/16	0.9375	23.8120
29/64	0.453125	11.5091	61/64	0.953125	24.2089
15/32	0.46875	11.9060	31/32	0.96875	24.6057
31/64	0.484375	12.3029	63/64	0.984375	25.0026
1/2	0.5	12.6997	1	1.0	25.3995

EQUIVALENTS OF ENGLISH INCHES IN MILLIMETERS (39.37 inches = 1 meter)

Inch	0	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$	Inch
0	0.0	1.6	3.2	4.8	6.4	7.9	9.5	11.1	12.7	14.3	15.9	17.5	19.1	20.6	22.2	23.8	0
1	25.4	27.0	28.6	30.2	31.7	33.3	34.9	36.5	38.1	39.7	41.3	42.9	44.4	46.0	47.6	49.2	1
2	50.8	52.4	54.0	55.6	57.1	58.7	60.3	61.9	63.5	65.1	66.7	68.3	69.8	71.4	73.0	74.6	2
3	76.2	77.8	79.4	81.0	82.5	84.1	85.7	87.3	88.9	90.5	92.1	93.7	95.2	96.8	98.4	100.0	3
4	101.6	103.2	104.8	106.4	108.0	109.5	111.1	112.7	114.3	115.9	117.5	119.1	120.7	122.2	123.8	125.4	4
5	127.0	128.6	130.2	131.8	133.4	134.9	136.5	138.1	139.7	141.3	142.9	144.5	146.1	147.6	149.2	150.8	5
6	152.4	154.0	155.6	157.2	158.8	160.3	161.9	163.5	165.1	166.7	168.3	169.9	171.5	173.0	174.6	176.2	6
7	177.8	179.4	181.0	182.6	184.2	185.7	187.3	188.9	190.5	192.1	193.7	195.3	196.9	198.4	200.0	201.6	7
8	203.2	204.8	206.4	208.0	209.6	211.1	212.7	214.3	215.9	217.5	219.1	220.7	222.3	223.8	225.4	227.0	8
9	228.6	230.2	231.8	233.4	235.0	236.5	238.1	239.7	241.3	242.9	244.5	246.1	247.7	249.2	250.8	252.4	9
10	254.0	255.6	257.2	258.8	260.4	261.9	263.5	265.1	266.7	268.3	269.9	271.5	273.1	274.6	276.2	277.8	10
11	279.4	281.0	282.6	284.2	285.7	287.3	288.9	290.5	292.1	293.7	295.3	296.9	298.4	300.0	301.6	303.2	11
12	304.8	306.4	308.0	309.6	311.1	312.7	314.3	315.9	317.5	319.1	320.7	322.3	323.8	325.4	327.0	328.6	12
13	330.2	331.8	333.4	335.0	336.5	338.1	339.7	341.3	342.9	344.5	346.1	347.7	349.2	350.8	352.4	354.0	13
14	355.6	357.2	358.8	360.4	361.9	363.5	365.1	366.7	368.3	369.9	371.5	373.1	374.6	376.2	377.8	379.4	14
15	381.0	382.6	384.2	385.8	387.3	388.9	390.5	392.1	393.7	395.3	396.9	398.5	400.0	401.6	403.2	404.8	15
16	406.4	408.0	409.6	411.2	412.7	414.3	415.9	417.5	419.1	420.7	422.3	423.9	425.4	427.0	428.6	430.2	16
17	431.8	433.4	435.0	436.6	438.1	439.7	441.3	442.9	444.5	446.1	447.7	449.3	450.8	452.4	454.0	455.6	17
18	457.2	458.8	460.4	462.0	463.5	465.1	466.7	468.3	469.9	471.5	473.1	474.7	476.2	477.8	479.4	481.0	18
19	482.6	484.2	485.8	487.4	488.9	490.5	492.1	493.7	495.3	496.9	498.5	500.1	501.6	503.2	504.8	506.4	19
20	508.0	509.6	511.2	512.8	514.3	515.9	517.5	519.1	520.7	522.3	523.9	525.5	527.0	528.6	530.2	531.8	20
21	533.4	535.0	536.6	538.2	539.7	541.3	542.9	544.5	546.1	547.7	549.3	550.9	552.4	554.0	555.6	557.2	21
22	558.8	560.4	562.0	563.6	565.1	566.7	568.3	569.9	571.5	573.1	574.7	576.3	577.8	579.4	581,0	582.6	22
23	584.2	585.8	587.4	589.0	590.5	592.1	593.7	595.3	596.9	598.5	600.1	601.7	603.2	604.8	606.4	608.0	23

COMPARISON OF STANDARD LINEAR UNITS—Approximate Values

A	One Milli.	One Centi.	One Inch	One Decim.	One Foot	One Yard	One Meter	One Rod	One Chain	One Hek-tom.	One Fur-long	One Kilo.	One Mile	One Knot	A
	Equals	Equals	Equals	Equals	Equals	Equals	Equals	Equals	Equals	Equals	Equals	Equals	Equals	Equals	
Milli.	1	10	25.4	100	304.80	914.40	1000	5029.2	20116.8	100,000	201,168	1,000,000	1,609,347	1,855,037	Milli.
Centi.	1/10 .1	1	2.54	10	30.48	91.44	100	502.9	2011.68	10,000	20116.8	100,000	160,934	185,325	Centi.
Inches	1/25 0.03937	4/10 0.3937	1	3.937	12	36	39.37	198	792	3937.	7920	39,370	63,360	73,033	Inches
Decim.	1/100 0.01	1/10 0.1	0.254	1	3.048	9.144	10	50.29	201.16	1000	2011.7	10,000	16,093	18,532	Decim.
Feet	0.00328	1/30 0.03280	1/12 0.0833⅓	1/3 ± 0.32808	1	3	3.2808 3'-3⅜"-	16.5	66	328.08	660	3280.8	5280	6080.2	Feet
Yards	0.00109	0.01093	1/36 0.0278	1/9 0.10936	1/3 0.333⅓	1	1.0936	5.5	22	109.36	220	1093.6	1760	2026.7	Yards
Meters	1/1000 0.001	1/100 0.01	1/40 0.02540	1/10 0.1	3/10 0.30480	9/10 0.91440	1	5.0292	20.116	100	201.17	1000	1609.3	1853.2	Meters
Rods	0.00019	0.00198	1/198 0.00505	0.01988	2/33 0.06060	2/11 0.18181	0.19883	1	4	19.883	40	198.83	320	368.85	Rods
Chains	1/20000 .00005-	1/2008 0.00049	1/792 0.00126	0.00497	1/66 0.01515	1/22 0.04545	0.04970	1/4 0.25	1	4.9708	10	49.708	80	92.23	Chains
Hektom.	1/100000	1/10000	1/3937 0.000254	1/1000	0.00305	0.00914	1/100	0.05029	0.20117	1	2.0117	10	16.093	18.53+	Hectom.
Furlongs	1/200000	1/20000	1/7920 .00012+	1/2000	1/660 0.00151	1/220 0.00454	0.00497	1/40 0.025	1/10	0.49078	1	4.9708	8	9.223	Furlongs
Kilo.		1/100000	1/39370 0.000025	1/10000	0.00030	0.00091	1/1000	0.00503	0.020117	1/10	0.20117	1	1.6093+	1.853+	Kilo.
Miles			1/63360		1/5280	1/1760 0.00056	0.00062	1/320 0.00312	1/80 0.0125	0.06213	1/8 0.125	5/8 0.62137	1	1.151+	Miles
Knots (U. S.)			1/73033		0.00016	0.00049	0.00054	0.00271	0.01084	0.05396	0.10844	0.5396+	App. 7/8 0.8684+	1	Knots (U. S.)

NOTE: At the point where any vertical column crosses any horizontal column will be found the value of the **UNIT** named at the head of the vertical column expressed in terms of the **UNIT** named under A opposite the horizontal column. Thus, under 1 meter find 1.0936 yards; under 1 foot find 0.3048 meter.

Decimal Equivalents of Fractions below ½"

Decimal Equivalents	Fractional Parts of an Inch										Decimal Equivalents
	6	7	8	12	14	16	24	28	32	64	
.015625										1	.015625
.03125									1	2	.03125
.035714								1			.035714
.041667							1				.041667
.046875										3	.046875
.0625						1			2	4	.0625
.071429					1			2			.071429
.078125										5	.078125
.083333				1			2				.083333
.09375									3	6	.09375
.107143								3			.107143
.109375										7	.109375
.125			1			2	3		4	8	.125
.140625										9	.140625
.142857		1			2			4			.142857
.15625									5	10	.15625
.166666	1			2			4				.166666
.171875										11	.171875
.178571								5			.178571
.1875						3			6	12	.1875
.203125										13	.203125
.208333							5				.208333
.214286					3			6			.214286
.21875									7	14	.21875
.234375										15	.234375
.25			2	3		4	6	7	8	16	.25
.265625										17	.265625
.28125									9	18	.28125
.285714		2			4			8			.285714
.291666							7				.291666
.296875										19	.296875
.3125						5			10	20	.3125
.321429								9			.321429
.328125										21	.328125
.333333	2			4			8				.333333
.34375									11	22	.34375
.357143					5			10			.357143
.359375										23	.359375
.375			3			6	9		12	24	.375
.390625										25	.390625
.392857								11			.392857
.40625									13	26	.40625
.41666				5			10				.41666
.421875										27	.421875
.428571		3			6			12			.428571
.4375						7			14	28	.4375
.453125										29	.453125
.458333							11				.458333
.464286								13			.464286
.46875									15	30	.46875
.484375										31	.484375
.5	3		4	6	7	8	12	14	16	32	.5

DECIMAL EQUIVALENTS OF FRACTIONS BETWEEN ½″ AND 1″

Decimal Equivalents	Fractional Parts of an Inch										Decimal Equivalents
	6	7	8	12	14	16	24	28	32	64	
.515625										33	.515625
.53125									17	34	.53125
.535714								15			.535714
.541666							13				.541666
.546875										35	.546875
.5625						9			18	36	.5625
.571429		4			8			16			.571429
.578125										37	.578125
.583333				7			14				.583333
.59375									19	38	.59375
.607143								17			.607143
.609375										39	.609375
.625			5			10	15		20	40	.625
.640625										41	.640625
.642867					9			18			.642867
.65625									21	42	.65625
.666666	4			8			16				.666666
.671875										43	.671875
.678571								19			.678571
.6875						11			22	44	.6875
.703125										45	.703125
.708333							17				.708333
.714286		5			10			20			.714286
.71875									23	46	.71875
.734375										47	.734375
.75			6	9		12	18	21	24	48	.75
.765625										49	.765625
.78125									25	50	.78125
.785714					11			22			.785714
.791666							19				.791666
.796875										51	.796875
.8125						13			26	52	.8125
.821429								23			.821429
.828125										53	.828125
.833333	5			10			20				.833333
.84375									27	54	.84375
.857143		6			12			24			.857143
.859375										55	.859375
.875			7			14	21		28	56	.875
.890625										57	.890625
.892857								25			.892857
.90625									29	58	.90625
.916666				11			22				.916666
.921875										59	.921875
.928571					13			26			.928571
.9375						15			30	60	.9375
.953125										61	.953125
.958333							23				.958333
.964286								27			.964286
.96875									31	62	.96875
.984375										63	.984375

WATER CONVERSION FACTORS

U. S. gallons × 8.33 = pounds.
U. S. gallons × 0.13368 = cubic feet.
U. S. gallons × 231 = cubic inches.
U. S. gallons × 0.83 = English gallons
U. S. gallons × 3.78 = liters.

English gallons (Imperial) × 10 = pounds.
English gallons (Imperial) × 0.16 = cubic feet.
English gallons (Imperial) × 277.274 = cubic inches.
English gallons (Imperial) × 1.2 = U. S. gallons.
English gallons (Imperial) × 4.537 = liters.

Cubic inches of water (39.1°) × 0.036125 = pounds.
Cubic inches of water (39.1°) × 0.004329 = U. S. gallons.
Cubic inches of water (39.1°) × 0.003607 = English gallons.
Cubic inches of water (39.1°) × 0.576384 = ounces.

Cubic feet (of water) (39.1°) × 62.425 = pounds.
Cubic feet (of water) (39.1°) × 7.48 = U. S. gallons.
Cubic feet (of water) (39.1°) × 6.232 = English gallons.
Cubic feet (of water) (39.1°) × 0.028 = tons.

Pounds of water × 27.72 = cubic inches.
Pounds of water × 0.01602 = cubic feet.
Pounds of water × 0.12 = U. S. gallons.
Pounds of water × 0.10 = English gallons.

CONVENIENT MULTIPLIERS

Inches × 0.08333 = feet.
Inches × 0.02778 = yards.
Inches × 0.00001578 = miles.

Feet × 0.3334 = yards.
Feet × 0.00019 = miles.

Yards × 36 = inches.
Yards × 3 = feet.
Yards × 0.0005681 = miles.

Miles × 63360 = inches.
Miles × 5280 = feet.
Miles × 1760 = yards.

Avoir. oz. × 0.0625 = pounds.
Avoir. oz. × 0.00003125 = tons.
Avoir. lbs. × 16 = ounces.

Sq. inches × 0.00695 = Sq. feet.
Sq. inches × 0.0007716 = Sq. yards
Cu. inches × 0.00058 = Cu. feet.
Cu. inches × 0.0000214 = Cu. yards

Sq. feet × 144 = Sq. inches.
Sq. feet × 0.1112 = Sq. yards.

Cu. feet × 1728 = Cu. inches
Cu. feet × 0.03704 = Cu. yards.
Sq. yards × 1296 = Sq. inches.

Sq. yards × 9 = Sq. feet.
Cu. yards × 46656 = Cu. inches.
Cu. yards × 27 = Cu. feet.

Avoir. lbs. × 0.0005 = tons.
Avoir. tons × 32000 = ounces.
Avoir. tons × 2000 = pounds.

TABLE OF PRIME-NUMBER FRACTIONS

THE table shows decimal equivalents of common fractions having prime numbers for both numerator and denominator. As an example, suppose it is required to find the thread angle of a worm.

$$\textit{Tangent thread angle} = \frac{\textit{Number threads}}{\textit{Diametral pitch} \times \textit{pitch diameter}}.$$

Find the angle of a worm 7 diametral pitch, 5 threads, 2-inch P. diameter:

$$\textit{Tangent angle} = \tfrac{5}{7} \times \tfrac{1}{2}$$

Then from table

$$\tfrac{5}{7} = 0.7143 \text{ and } \frac{0.7143}{2} = 0.35715$$

which is the tangent for 19 degrees 39 minutes, nearly.

PRIME NUMBER FRACTIONS AND THEIR DECIMAL EQUIVALENTS

Denominators (Prime Numbers Only)

Numerators (Prime Numbers only)	97	89	83	79	73	71	67	61	59	53	47	43
1	.0103	.0112	.0120	.0126	.0137	.0141	.0149	.0164	.0169	.0189	.0213	.0233
3	.0309	.0337	.0361	.0380	.0411	.0423	.0448	.0492	.0508	.0566	.0638	.0698
5	.0515	.0562	.0602	.0633	.0685	.0704	.0746	.0820	.0847	.0943	.1064	.1163
7	.0722	.0787	.0843	.0886	.0959	.0986	.1045	.1148	.1186	.1321	.1489	.1628
11	.1134	.1236	.1325	.1392	.1507	.1549	.1642	.1803	.1864	.2075	.2340	.2558
13	.1340	.1461	.1566	.1646	.1781	.1831	.1940	.2131	.2203	.2453	.2766	.3023
17	.1753	.1910	.2048	.2152	.2329	.2394	.2537	.2787	.2881	.3208	.3617	.3953
19	.1959	.2135	.2289	.2405	.2603	.2676	.2836	.3115	.3220	.3585	.4043	.4419
23	.2371	.2584	.2771	.2911	.3151	.3299	.3433	.3770	.3898	.4340	.4894	.5349
29	.2990	.3258	.3494	.3671	.3973	.4085	.4328	.4754	.4915	.5472	.6170	.6744
31	.3196	.3483	.3735	.3924	.4247	.4366	.4627	.5082	.5254	.5849	.6596	.7209
37	.3814	.4157	.4458	.4684	.5068	.5211	.5522	.6066	.6271	.6981	.7872	.8605
41	.4227	.4607	.4940	.5190	.5616	.5775	.6119	.6721	.6949	.7736	.8723	.9535
43	.4433	.4831	.5181	.5443	.5890	.6056	.6418	.7049	.7288	.8113	.9149	
47	.4845	.5281	.5663	.5949	.6438	.6620	.7015	.7705	.7966	.8868		
53	.5464	.5955	.6386	.6709	.7260	.7465	.7910	.8689	.8983			
59	.6082	.6629	.7108	.7468	.8082	.8310	.8806	.9672				
61	.6289	.6854	7349	.7722	.8356	.8592	.9104					
67	.6907	.7528	.8072	.8481	.9178	.9437						
71	.7320	7978	.8554	.8987	.9726							
73	.7526	.8202	.8795	.9241								
79	.8144	.8876	.9518									
83	.8557	.9326										
89	.9175											

Denominators (Prime Numbers Only)

Numerators (Prime Numbers only)	41	37	31	29	23	19	17	13	11	7	5	3
1	.0244	.0270	.0323	.0345	.0435	.0526	.0588	.0769	.0909	.1429	.2000	.3333
3	.0732	.0811	.0968	.1034	.1304	.1579	.1765	.2308	.2727	.4286	.6000	
5	.1220	.1351	.1613	.1724	.2174	.2632	.2941	.3846	.4545	.7143		
7	.1707	.1892	.2258	.2414	.3043	.3684	.4118	.5385	.6364			
11	.2683	.2973	.3548	.3793	.4783	.5789	.6471	.8462				
13	.3171	.3514	.4194	.4483	.5652	.6842	.7647					
17	.4146	.4595	.5484	.5862	.7391	.8947						
19	.4634	.5135	.6129	.6552	.8261							
23	.5610	.6212	.7419	.7931								
29	.7073	.7838	.9355									
31	.7561	.8378										
37	.9024											

Only those common fractions having prime numbers for both the numerator and denominator are given in table. Others can be found by simple multiplication or division.

Decimal Equivalents of Fractions and Nearest Equivalent 64ths

Fr.	Decimal	Nearest 64th	Fr.	Decimal	Nearest 64th	Fr.	Decimal	Nearest 64th
1/32	0.0313		2/15	0.1333	1/8	7/27	0.2593	
1/31	0.0323		3/22	0.1364		6/23	0.2609	
1/30	0.0333		4/29	0.1379		5/19	0.2632	
1/29	0.0345	1/32	1/7	0.1429	9/64	4/15	0.2667	17/64
1/28	0.0357		4/27	0.1481		7/26	0.2692	
1/27	0.0370		3/20	0.1500		3/11	0.2727	
1/26	0.0385		2/13	0.1538		8/29	0.2759	
1/25	0.0400		5/32	0.1563	5/32	5/18	0.2778	
1/24	0.0417		3/19	0.1579		7/25	0.2800	
1/23	0.0435		4/25	0.1600		9/32	0.2813	9/32
1/22	0.0455		5/31	0.1613		2/7	0.2857	
1/21	0.0476	3/64	1/6	0.1667		9/31	0.2903	
1/20	0.0500		5/29	0.1724	11/64	7/24	0.2917	
1/19	0.0526		4/23	0.1739		5/17	0.2941	
1/18	0.0556		3/17	0.1765		8/27	0.2963	19/64
1/17	0.0589		5/28	0.1785		3/10	0.3000	
1/16	0.0625	1/16	2/11	0.1818		7/23	0.3043	
2/31	0.0645		5/27	0.1852		4/13	0.3077	
1/15	0.0667		3/16	0.1875	3/16	9/29	0.3103	
2/29	0.0690		4/21	0.1905		5/16	0.3125	5/16
1/14	0.0714		5/26	0.1923		6/19	0.3158	
2/27	0.0740		6/31	0.1935		7/22	0.3182	
1/13	0.0769	5/64	1/5	0.2000	13/64	8/25	0.3200	
2/25	0.0800		6/29	0.2069		9/28	0.3214	
1/12	0.0833		5/24	0.2083		10/31	0.3226	21/64
2/23	0.0870		4/19	0.2105		1/3	0.3333	
1/11	0.0909		3/14	0.2143		11/32	0.3438	11/32
3/32	0.0938	3/32	5/23	0.2174		10/29	0.3448	
2/21	0.0952		7/32	0.2188	7/32	9/26	0.3462	
3/31	0.0968		2/9	0.2222		8/23	0.3478	
1/10	0.1000		7/31	0.2258		7/20	0.3500	
3/29	0.1034		5/22	0.2273		6/17	0.3529	
2/19	0.1053		3/13	0.2308		11/31	0.3548	
3/28	0.1071		7/30	0.2333	15/64	5/14	0.3571	
1/9	0.1111	7/64	4/17	0.2353		9/25	0.3600	23/64
3/26	0.1154		5/21	0.2381		4/11	0.3636	
2/17	0.1176		6/25	0.2400		11/30	0.3667	
3/25	0.1200		7/29	0.2414		7/19	0.3684	
1/8	0.1250	1/8	1/4	0.2500	1/4	10/27	0.3704	
4/31	0.1290		8/31	0.2580		3/8	0.3750	3/8
3/23	0.1304							

DECIMAL EQUIVALENTS OF FRACTIONS AND NEAREST EQUIVALENT 64THS

Fr.	Decimal	Near-est 64th	Fr.	Decimal	Near-est 64th	Fr.	Decimal	Near-est 64th
11/29	0.3793	3/8	16/31	0.5161	33/64	17/27	0.6296	5/8
8/21	0.3810		15/29	0.5172		12/19	0.6316	
5/13	0.3846		14/27	0.5185		19/30	0.6333	
12/31	0.3871		13/25	0.5200		7/11	0.6364	
7/18	0.3889		12/23	0.5217		16/25	0.6400	41/64
9/23	0.3913	25/64	11/21	0.5238		9/14	0.6429	
11/28	0.3929		10/19	0.5263		20/31	0.6452	
2/5	0.4000		9/17	0.5294		11/17	0.6471	
13/32	0.4063	13/32	17/32	0.5313	17/32	13/20	0.6500	
11/27	0.4074		8/15	0.5333		15/23	0.6522	
9/22	0.4091		15/28	0.5357		17/26	0.6538	
7/17	0.4118		7/13	0.5385		19/29	0.6552	
12/29	0.4138		13/24	0.5417		21/32	0.6563	21/32
5/12	0.4167		6/11	0.5455	35/64	2/3	0.6667	43/64
13/31	0.4194		17/31	0.5484		21/31	0.6774	
8/19	0.4211	27/64	11/20	0.5500		19/28	0.6786	
11/26	0.4231		16/29	0.5517		17/25	0.6800	
3/7	0.4286		5/9	0.5556		15/22	0.6818	
13/30	0.4333		14/25	0.5600		13/19	0.6842	
10/23	0.4348		9/16	0.5625	9/16	11/16	0.6875	11/16
7/16	0.4375	7/16	13/23	0.5652		20/29	0.6897	
11/25	0.4400		17/30	0.5667		9/13	0.6923	
4/9	0.4444		4/7	0.5714		16/23	0.6957	
13/29	0.4483		15/26	0.5769		7/10	0.7000	
9/20	0.4500		11/19	0.5789	37/64	19/27	0.7037	45/64
14/31	0.4516	29/64	18/31	0.5806		12/17	0.7059	
5/11	0.4545		7/12	0.5833		17/24	0.7083	
11/24	0.4583		17/29	0.5862		22/31	0.7097	
6/13	0.4615		10/17	0.5882		5/7	0.7143	
13/28	0.4642		13/22	0.5909		23/32	0.7188	23/32
7/15	0.4667		16/27	0.5926		18/25	0.7200	
15/32	0.4688	15/32	19/32	0.5938	19/32	13/18	0.7222	
8/17	0.4706		3/5	0.6000		21/29	0.7241	
9/19	0.4737		17/28	0.6071		8/11	0.7273	
10/21	0.4762		14/23	0.6087	39/64	19/26	0.7308	
11/23	0.4783		11/18	0.6111		11/15	0.7333	47/64
12/25	0.4800		19/31	0.6129		14/19	0.7368	
13/27	0.4815		8/13	0.6154		17/23	0.7391	
14/29	0.4828	31/64	13/21	0.6190		20/27	0.7407	
15/31	0.4839		18/29	0.6207		23/31	0.7419	
1/2	0.5000	1/2	5/8	0.6250	5/8	3/4	0.7500	3/4

DECIMAL EQUIVALENTS OF FRACTIONS AND NEAREST EQUIVALENT 64THS

Fr.	Decimal	Nearest 64th	Fr.	Decimal	Nearest 64th	Fr.	Decimal	Nearest 64th
22/29	0.7586	49/64	26/31	0.8387	27/32	11/12	0.9167	59/64
19/25	0.7600		21/25	0.8400		23/25	0.9200	
16/21	0.7619		16/19	0.8421		12/13	0.9231	
13/17	0.7647		27/32	0.8438		25/27	0.9259	
23/30	0.7667		11/13	0.8462		13/14	0.9286	
10/13	0.7692		17/20	0.8500		27/29	0.9310	15/16
17/22	0.7727		23/27	0.8519	55/64	14/15	0.9333	
24/31	0.7742	25/32	6/7	0.8571		29/31	0.9355	
7/9	0.7778		25/29	0.8621		15/16	0.9375	
25/32	0.7813		19/22	0.8636		16/17	0.9412	
18/23	0.7826		13/15	0.8667	7/8	17/18	0.9444	
11/14	0.7857		20/23	0.8696		18/19	0.9474	61/64
15/19	0.7895	51/64	27/31	0.8710		19/20	0.9500	
19/24	0.7917		7/8	0.8750		20/21	0.9524	
23/29	0.7931		22/25	0.8800		21/22	0.9545	
4/5	0.8000		15/17	0.8824		22/23	0.9565	
25/31	0.8065	13/16	23/26	0.8846	57/64	23/24	0.9583	
21/26	0.8077		8/9	0.8889		24/25	0.9600	
17/21	0.8095		25/28	0.8929		25/26	0.9615	31/32
13/16	0.8125		17/19	0.8947		26/27	0.9630	
22/27	0.8148		26/29	0.8966		27/28	0.9643	
9/11	0.8182		9/10	0.9000	29/32	28/29	0.9655	
23/28	0.8214	53/64	28/31	0.9032		29/30	0.9667	
14/17	0.8235		19/21	0.9048		30/31	0.9678	
19/23	0.8261		29/32	0.9063		31/32	0.9688	
24/29	0.8276		10/11	0.9091		32/32	1.0000	
5/6	0.8334		21/23	0.9130				

Equivalents of Inches and Fractions of Inches in Decimals of a Foot

In.	0 In.	1 In.	2 In.	3 In.	4 In.	5 In.
		.0833	.1667	.2500	.3333	.4167
1/32	.0026	.0859	.1693	.2526	.3359	.4193
1/16	.0052	.0885	.1719	.2552	.3385	.4219
3/32	.0078	.0911	.1745	.2578	.3411	.4245
1/8	.0104	.0938	.1771	.2604	.3438	.4271
5/32	.0130	.0964	.1797	.2630	.3464	.4297
3/16	.0156	.0990	.1823	.2656	.3490	.4323
7/32	.0182	.1016	.1849	.2682	.3516	.4349
1/4	.0208	.1042	.1875	.2708	.3542	.4375
9/32	.0234	.1068	.1901	.2734	.3568	.4401
5/16	.0260	.1094	.1927	.2760	.3594	.4427
11/32	.0286	.1120	.1953	.2786	.3620	.4453
3/8	.0313	.1146	.1979	.2813	.3646	.4479
13/32	.0339	.1172	.2005	.2839	.3672	.4505
7/16	.0365	.1198	.2031	.2865	.3698	.4531
15/32	.0391	.1224	.2057	.2891	.3724	.4557
1/2	.0417	.1253	.2083	.2917	.3750	.4583
17/32	.0443	.1276	.2091	.2943	.3776	.4609
9/16	.0469	.1302	.2135	.2969	.3802	.4635
19/32	.0495	.1328	.2161	.2995	.3828	.4661
5/8	.0521	.1354	.2188	.3021	.3854	.4688
21/32	.0547	.1380	.2214	.3047	.3880	.4714
11/16	.0573	.1406	.2240	.3073	.3906	.4740
23/32	.0599	.1432	.2266	.3099	.3932	.4766
3/4	.0625	.1458	.2292	.3125	.3958	.4792
25/32	.0651	.1484	.2318	.3151	.3984	.4818
13/16	.0677	.1510	.2344	.3177	.4010	.4844
27/32	.0703	.1536	.2370	.3203	.4036	.4870
7/8	.0729	.1563	.2396	.3229	.4063	.4896
29/32	.0755	.1589	.2422	.3255	.4089	.4922
15/16	.0781	.1615	.2448	.3281	.4115	.4948
31/32	.0807	.1641	.2474	.3307	.4141	.4974

EQUIVALENTS OF INCHES AND FRACTIONS OF INCHES IN DECIMALS OF A FOOT

In.	6 In.	7 In.	8 In.	9 In.	10 In.	11 In.
	.5000	.5833	.6667	.7500	.8333	.9167
1/32	.5026	.5859	.6693	.7526	.8359	.9193
1/16	.5052	.5885	.6719	.7552	.8385	.9219
3/32	.5078	.5911	.6745	.7578	.8411	.9245
1/8	.5104	.5938	.6771	.7604	.8438	.9271
5/32	.5130	.5964	.6797	.7630	.8464	.9297
3/16	.5156	.5990	.6823	.7656	.8490	.9323
7/32	.5182	.6016	.6849	.7682	.8516	.9349
1/4	.5208	.6042	.6875	.7708	.8542	.9375
9/32	.5234	.6068	.6901	.7734	.8568	.9401
5/16	.5260	.6094	.6927	.7760	.8594	.9427
11/32	.5286	.6120	.6953	.7786	.8620	.9453
3/8	.5313	.6146	.6979	.7813	.8646	.9479
13/32	.5339	.6172	.7005	.7839	.8672	.9505
7/16	.5365	.6198	.7031	.7865	.8698	.9531
15/32	.5391	.6224	.7057	.7891	.8724	.9557
1/2	.5417	.6250	.7083	.7917	.8750	.9583
17/32	.5443	.6276	.7109	.7943	.8776	.9609
9/16	.5469	.6302	.7135	.7969	.8802	.9635
19/32	.5495	.6328	.7161	.7995	.8828	.9661
5/8	.5521	.6354	.7188	.8021	.8854	.9688
21/32	.5547	.6380	.7214	.8047	.8880	.9714
11/16	.5573	.6406	.7240	.8073	.8906	.9740
23/32	.5599	.6432	.7266	.8099	.8932	.9766
3/4	.5625	.6458	.7292	.8125	.8958	.9792
25/32	.5651	.6484	.7318	.8151	.8984	.9818
13/16	.5677	.6510	.7344	.8177	.9010	.9844
27/32	.5703	.6536	.7370	.8203	.9036	.9870
7/8	.5729	.6563	.7396	.8229	.9063	.9896
29/32	.5755	.6589	.7422	.8255	.9089	.9922
15/16	.5781	.6615	.7448	.8281	.9115	.9948
31/32	.5807	.6641	.7474	.8307	.9141	.9974

DECIMAL EQUIVALENTS OF FRACTIONS OF AN INCH. (ADVANCING BY 8THS, 16THS, 32NDS AND 64THS.)

8ths, and 16ths	32nds	64ths	64ths
$\frac{1}{8}$ = .125	$\frac{1}{32}$ = .03125	$\frac{1}{64}$ = .015625	$\frac{33}{64}$ = .515625
$\frac{1}{4}$ = .250	$\frac{3}{32}$ = .09375	$\frac{3}{64}$ = .046875	$\frac{35}{64}$ = .546875
$\frac{3}{8}$ = .375	$\frac{5}{32}$ = .15625	$\frac{5}{64}$ = .078125	$\frac{37}{64}$ = .578125
$\frac{1}{2}$ = .500	$\frac{7}{32}$ = .21875	$\frac{7}{64}$ = .109375	$\frac{39}{64}$ = .609375
$\frac{5}{8}$ = .625	$\frac{9}{32}$ = .28125	$\frac{9}{64}$ = .140625	$\frac{41}{64}$ = .640625
$\frac{3}{4}$ = .750	$\frac{11}{32}$ = .34375	$\frac{11}{64}$ = .171875	$\frac{43}{64}$ = .671875
$\frac{7}{8}$ = .875	$\frac{13}{32}$ = .40625	$\frac{13}{64}$ = .203125	$\frac{45}{64}$ = .703125
	$\frac{15}{32}$ = .46875	$\frac{15}{64}$ = .234375	$\frac{47}{64}$ = .734375
16ths.			
$\frac{1}{16}$ = .0625	$\frac{17}{32}$ = .53125	$\frac{17}{64}$ = .265625	$\frac{49}{64}$ = .765625
$\frac{3}{16}$ = .1875	$\frac{19}{32}$ = .59375	$\frac{19}{64}$ = .296875	$\frac{51}{64}$ = .796875
$\frac{5}{16}$ = .3125	$\frac{21}{32}$ = .65625	$\frac{21}{64}$ = .328125	$\frac{53}{64}$ = .828125
$\frac{7}{16}$ = .4375	$\frac{23}{32}$ = .71875	$\frac{23}{64}$ = .359375	$\frac{55}{64}$ = .859375
$\frac{9}{16}$ = .5625	$\frac{25}{32}$ = .78125	$\frac{25}{64}$ = .390625	$\frac{57}{64}$ = .890625
$\frac{11}{16}$ = .6875	$\frac{27}{32}$ = .84375	$\frac{27}{64}$ = .421875	$\frac{59}{64}$ = .921875
$\frac{13}{16}$ = .8125	$\frac{29}{32}$ = .90625	$\frac{29}{64}$ = .453125	$\frac{61}{64}$ = .953125
$\frac{15}{16}$ = .9375	$\frac{31}{32}$ = .96875	$\frac{31}{64}$ = .484375	$\frac{63}{64}$ = .984375

DECIMAL EQUIVALENTS OF FRACTIONS OF AN INCH. (ADVANCING BY 64THS.)

$\frac{1}{64}$ = .015625	$\frac{17}{64}$ = .265625	$\frac{33}{64}$ = .515625	$\frac{49}{64}$ = .765625
$\frac{1}{32}$ = .03125	$\frac{9}{32}$ = .28125	$\frac{17}{32}$ = .53125	$\frac{25}{32}$ = .78125
$\frac{3}{64}$ = .046875	$\frac{19}{64}$ = .296875	$\frac{35}{64}$ = .546875	$\frac{51}{64}$ = .796875
$\frac{1}{16}$ = .0625	$\frac{5}{16}$ = .3125	$\frac{9}{16}$ = .5625	$\frac{13}{16}$ = .8125
$\frac{5}{64}$ = .078125	$\frac{21}{64}$ = .328125	$\frac{37}{64}$ = .578125	$\frac{53}{64}$ = .828125
$\frac{3}{32}$ = .09375	$\frac{11}{32}$ = .34375	$\frac{19}{32}$ = .59375	$\frac{27}{32}$ = .84375
$\frac{7}{64}$ = .109375	$\frac{23}{64}$ = .359375	$\frac{39}{64}$ = .609375	$\frac{55}{64}$ = .859375
$\frac{1}{8}$ = .125	$\frac{3}{8}$ = .375	$\frac{5}{8}$ = .625	$\frac{7}{8}$ = .875
$\frac{9}{64}$ = .140625	$\frac{25}{64}$ = .390625	$\frac{41}{64}$ = .640625	$\frac{57}{64}$ = .890625
$\frac{5}{32}$ = .15625	$\frac{13}{32}$ = .40625	$\frac{21}{32}$ = .65625	$\frac{29}{32}$ = .90625
$\frac{11}{64}$ = .171875	$\frac{27}{64}$ = .421875	$\frac{43}{64}$ = .671875	$\frac{59}{64}$ = .921875
$\frac{3}{16}$ = .1875	$\frac{7}{16}$ = .4375	$\frac{11}{16}$ = .6875	$\frac{15}{16}$ = .9375
$\frac{13}{64}$ = .203125	$\frac{29}{64}$ = .453125	$\frac{45}{64}$ = .703125	$\frac{61}{64}$ = .953125
$\frac{7}{32}$ = .21875	$\frac{15}{32}$ = .46875	$\frac{23}{32}$ = .71875	$\frac{31}{32}$ = .96875
$\frac{15}{64}$ = .234375	$\frac{31}{64}$ = .484375	$\frac{47}{64}$ = .734375	$\frac{63}{64}$ = .984375
$\frac{1}{4}$ = .25	$\frac{1}{2}$ = .50	$\frac{3}{4}$ = .75	

SQUARING LARGE NUMBERS NOT IN THE TABLES

Numbers which are 1,000 greater than those in the tables, that is, numbers from 1,001 to 2,000, are quickly squared by means of a method which consists of two steps as follows:

1. To the number to be squared add a number which is smaller by 1,000. To this total add three ciphers to the right of the last figure.

2. From the tables take the figures representing the square of the smaller number and add them to the figures obtained in the first step. The sum is equal to the square of the larger number. For example, what is the square of 1,687? Using the method stated, we have:

1. 1,687
   687
   2,374 Adding three ciphers, we get 2,374,000

2. Pages 1133 to 1142 show the square of 687 equals 471,969. Adding this to 2,374,000 we have 2,845,969, which is the square of 1,687.

What is the square of 1,009 as figured by this method?

1. 1,009
   9
   1,018,000

2. The square of 9 is 81

1,018,000
81
1,018,081

1,009 squared equals 1,018,081.

All numbers are to be treated as whole numbers in obtaining squares. The placing of decimals, whenever necessary, is left until the final result is obtained. The usual rule for placing the decimal is then applied. For example, if the square of 1.687 had been desired, the result would have been 2.845,969.

SQUARE OF NUMBERS FROM "0" TO "$7\frac{63}{64}$" BY 64THS—NUMBER

Added Fractions to Sixty-fourths	0	1	2	3	4	5	6	7
0	.000000	1.00000	4.00000	9.00000	16.00000	25.00000	36.00000	49.00000
$\frac{1}{64}$	.000244	1.03149	4.06274	9.09399	16.12524	25.15649	36.18774	49.21899
$\frac{1}{32}$	.000977	1.06348	4.12598	9.18848	16.25098	25.31348	36.37598	49.43848
$\frac{3}{64}$	.002197	1.09595	4.18970	9.28345	16.37720	25.47095	36.56470	49.65845
$\frac{1}{16}$	.003906	1.12891	4.25391	9.37891	16.50391	25.62891	36.75391	49.87891
$\frac{5}{64}$	.006104	1.16235	4.31860	9.47485	16.63110	25.78735	36.94360	50.09985
$\frac{3}{32}$	.008789	1.19629	4.38379	9.57129	16.75879	25.94629	37.13379	50.32129
$\frac{7}{64}$	.011963	1.23071	4.44946	9.66821	16.88696	26.10571	37.32446	50.54321
$\frac{1}{8}$	.015625	1.26563	4.51563	9.76563	17.01563	26.26563	37.51563	50.76563
$\frac{9}{64}$	.019775	1.30103	4.58228	9.86353	17.14478	26.42603	37.70728	50.98853
$\frac{5}{32}$	.024414	1.33691	4.64941	9.96191	17.27441	26.58691	37.89941	51.21191
$\frac{11}{64}$	.029541	1.37329	4.71704	10.06079	17.40454	26.74829	38.09204	51.43579
$\frac{3}{16}$	.035156	1.41016	4.78516	10.16016	17.53516	26.91016	38.28516	51.66016
$\frac{13}{64}$	.041260	1.44751	4.85376	10.26001	17.66626	27.07251	38.47876	51.88501
$\frac{7}{32}$	.047852	1.48535	4.92285	10.36035	17.79785	27.23535	38.67285	52.11035
$\frac{15}{64}$	.054932	1.52368	4.99243	10.46118	17.92993	27.39868	38.86743	52.33618
$\frac{1}{4}$	.062500	1.56250	5.06250	10.56250	18.06250	27.56250	39.06250	52.56250
$\frac{17}{64}$	.070557	1.60181	5.13306	10.66431	18.19556	27.72681	39.25806	52.78931
$\frac{9}{32}$	.079102	1.64160	5.20410	10.76660	18.32910	27.89160	39.45410	53.01660
$\frac{19}{64}$	.088135	1.68188	5.27563	10.85938	18.46313	28.05688	39.65063	53.24438
$\frac{5}{16}$	.097656	1.72266	5.34766	10.97266	18.59766	28.22266	39.84766	53.47266
$\frac{21}{64}$	.107666	1.76392	5.42017	11.07642	18.73267	28.38892	40.04517	53.70142
$\frac{11}{32}$	.118164	1.80566	5.49316	11.18066	18.86816	28.55566	40.24316	53.93066
$\frac{23}{64}$	.129151	1.84790	5.56665	11.28540	19.00415	28.72290	40.44165	54.16040
$\frac{3}{8}$	.140625	1.89063	5.64063	11.39063	19.14063	28.89063	40.64063	54.39063
$\frac{25}{64}$	.152588	1.93384	5.71509	11.49634	19.27759	29.05884	40.84009	54.62134
$\frac{13}{32}$	.165039	1.97754	5.79004	11.60254	19.41504	29.22754	41.04004	54.85254
$\frac{27}{64}$	.177979	2.02173	5.86548	11.70923	19.55298	29.39673	41.24048	55.08423
$\frac{7}{16}$	.191406	2.06641	5.94141	11.81641	19.69141	29.56641	41.44141	55.31641
$\frac{29}{64}$	.205322	2.11157	6.01782	11.92407	19.83032	29.73657	41.64282	55.54907
$\frac{15}{32}$	.219726	2.15723	6.09473	12.03223	19.96973	29.90723	41.84473	55.78223
$\frac{31}{64}$	.234619	2.20337	6.17212	12.14087	20.10962	30.07837	42.04712	56.01587

SQUARE OF NUMBERS FROM "0" TO "$7\frac{63}{64}$" BY 64THS—NUMBER.—*Continued*

Added Fractions to Sixty-fourths	0	1	2	3	4	5	6	7
$\frac{1}{2}$	.250000	2.25000	6.25000	12.25000	20.25000	30.25000	42.25000	56.25000
$\frac{33}{64}$	.265869	2.29712	6.32837	12.35962	20.39087	30.42212	42.45337	56.48462
$\frac{17}{32}$	.282227	2.34473	6.40723	12.46973	20.53223	30.59473	42.65723	56.71973
$\frac{35}{64}$	.299072	2.39282	6.48657	12.58032	20.67407	30.76782	42.86157	56.95532
$\frac{9}{16}$	.316406	2.44141	6.56641	12.69141	20.81641	30.94141	43.06641	57.19141
$\frac{37}{64}$	.334229	2.49048	6.64673	12.80298	20.95923	31.11548	43.27173	57.42798
$\frac{19}{32}$	.352539	2.54004	6.72754	12.91504	21.10254	31.29004	43.47754	57.66504
$\frac{39}{64}$	.371338	2.59009	6.80884	13.02759	21.24634	31.46509	43.68384	57.90259
$\frac{5}{8}$	.390625	2.64063	6.89063	13.14063	21.39063	31.64063	43.89063	58.14063
$\frac{41}{64}$	.410400	2.69165	6.97290	13.25415	21.53540	31.81665	44.09790	58.37915
$\frac{21}{32}$	.430664	2.74316	7.05566	13.36816	21.68066	31.99316	44.30566	58.61816
$\frac{43}{64}$	.451416	2.79517	7.13892	13.48267	21.82642	32.17017	44.51392	58.85767
$\frac{11}{16}$	.472656	2.84766	7.22266	13.59766	21.97266	32.34766	44.72266	59.09766
$\frac{45}{64}$	.494385	2.90063	7.30688	13.71313	22.11938	32.52563	44.93188	59.33813
$\frac{23}{32}$	.516602	2.95410	7.39160	13.82910	22.26660	32.70410	45.14160	59.57910
$\frac{47}{64}$	.539307	3.00806	7.47681	13.94556	22.41431	32.88306	45.35181	59.82056
$\frac{3}{4}$	.562500	3.06250	7.56250	14.06250	22.56250	33.06250	45.56250	60.06250
$\frac{49}{64}$	.586182	3.11743	7.64868	14.17993	22.71118	33.24243	45.77368	60.30493
$\frac{25}{32}$	.610352	3.17285	7.73535	14.29785	22.86035	33.42285	45.98535	60.54785
$\frac{51}{64}$	.635010	3.22876	7.82251	14.41626	23.01001	33.60376	46.19751	60.79126
$\frac{13}{16}$	.660156	3.28516	7.91016	14.53516	23.16016	33.78516	46.41016	61.03516
$\frac{53}{64}$	.685791	3.34204	7.99829	14.65454	23.31079	33.96704	46.62329	61.27954
$\frac{27}{32}$	.711914	3.39941	8.08691	14.77441	23.46191	34.14941	46.83691	61.52441
$\frac{55}{64}$	.738526	3.45728	8.17603	14.89478	23.61353	34.33228	47.05103	61.76978
$\frac{7}{8}$	.765625	3.51563	8.26563	15.01563	23.76563	34.51563	47.26563	62.01563
$\frac{57}{64}$	.793213	3.57446	8.35571	15.13696	23.91821	34.69946	47.48071	62.26196
$\frac{29}{32}$	.821289	3.63378	8.44629	15.25879	24.07129	34.88379	47.69629	62.50879
$\frac{59}{64}$	.849854	3.69360	8.53735	15.38110	24.22485	35.06860	47.91235	62.75610
$\frac{15}{16}$	.878906	3.75391	8.62891	15.50391	24.37891	35.25391	48.12891	63.00391
$\frac{61}{64}$	.908447	3.81470	8.72095	15.62720	24.53345	35.43970	48.34595	63.25220
$\frac{31}{32}$	.938477	3.87598	8.81348	15.75098	24.68848	35.62598	48.56348	63.50098
$\frac{63}{64}$	.968994	3.93774	8.90649	15.87524	24.84399	35.81274	48.78149	63.75024

Decimal Equivalents, Squares, Square Roots, Cubes, and Cube Roots of Fractions; Circumferences and Areas of Circles from 1/64 to 1 inch

Fraction	Dec. Equiv.	Square	Sq. Root	Cube	Cube Root	Circum. Circle	Area Circle
1/64	.015625	.000244	.1250	.000003815	.2500	.04909	.000192
1/32	.03125	.0009765	.1768	.00003052	.3150	.09818	.000767
3/64	.046875	.002197	.2165	.000103	.3606	.1473	.001726
1/16	.0625	.003906	.2500	.0002442	.3968	.1963	.003068
5/64	.078125	.006104	.2795	.0004768	.4275	.2455	.004794
3/32	.09375	.008789	.3062	.0008240	.4543	.2945	.006903
7/64	.109375	.01196	.3307	.001308	.4782	.3436	.009396
1/8	.1250	.01563	.3535	.001953	.5000	.3927	.01228
9/64	.140625	.01978	.3750	.002781	.5200	.4438	.01553
5/32	.15625	.02441	.3953	.003815	.5386	.4909	.01916
11/64	.171875	.02954	.4161	.005078	.5560	.5400	.02321
3/16	.1875	.03516	.4330	.006592	.5724	.5890	.02761
13/64	.203125	.04126	.4507	.008381	.5878	.6381	.03241
7/32	.21875	.04786	.4677	.01047	.6025	.6872	.03758
15/64	.234375	.05493	.4841	.01287	.6166	.7363	.04314
1/4	.2500	.0625	.5000	.01562	.6300	.7854	.04909
17/64	.265625	.07056	.5154	.01874	.6428	.8345	.05541
9/32	.28125	.07910	.5303	.02225	.6552	.8836	.06213
19/64	.296875	.08813	.5449	.02616	.6671	.9327	.06922
5/16	.3125	.09766	.5590	.03052	.6786	.9817	.07670
21/64	.328125	.1077	.5728	.03533	.6897	1.031	.08456
11/32	.34375	.1182	.5863	.04062	.7005	1.080	.09281
23/64	.359375	.12913	.5995	.04641	.7110	1.129	.1014
3/8	.3750	.1406	.6124	.05273	.7211	1.178	.1104
25/64	.390625	.1526	.6250	.05960	.7310	1.227	.1226
13/32	.40625	.1650	.6374	.06705	.7406	1.276	.1296
27/64	.421875	.17800	.6495	.07508	.7500	1.325	.1398
7/16	.4375	.1914	.6614	.08374	.7592	1.374	.1503
29/64	.453125	.2053	.6732	.09304	.7681	1.424	.1613
15/32	.46875	.2197	.6847	.1030	.7768	1.473	.1726
31/64	.484375	.2346	.6960	.1136	.7853	1.522	.1843
1/2	.5000	.2500	.7071	.1250	.7937	1.571	.1963

DECIMAL EQUIVALENTS, SQUARES, SQUARE ROOTS, CUBES, CUBE ROOTS OF FRACTIONS; CIRCUMFERENCES AND AREAS OF CIRCLES FROM $\frac{1}{64}$ TO 1 INCH

Fraction	Dec. Equiv.	Square	Sq. Root	Cube	Cube Root	Circum. Circle	Area Circle
$\frac{33}{64}$	.515625	.2659	.7181	.1371	.8019	1.620	.2088
$\frac{17}{32}$	.53125	.2822	.7289	.1499	.8099	1.669	.2217
$\frac{35}{64}$	.546875	.2991	.7395	.1636	.8178	1.718	.2349
$\frac{9}{16}$	.5625	.3164	.7500	.1780	.8255	1.767	.2485
$\frac{37}{64}$	.578125	.3342	.7603	.1932	.8331	1.816	.2625
$\frac{19}{32}$	.59375	.3525	.7706	.2093	.8405	1.865	.2769
$\frac{39}{64}$	.609375	.3713	.7806	.2263	.8478	1.914	.2916
$\frac{5}{8}$	.6250	.3906	.7906	.2441	.8550	1.963	.3068
$\frac{41}{64}$	.640625	.4104	.8004	.2629	.8621	2.013	.3223
$\frac{21}{32}$	.65625	.4307	.8101	.2826	.8690	2.062	.3382
$\frac{43}{64}$	.671875	.4514	.8197	.3033	.8758	2.111	.3545
$\frac{11}{16}$	.6875	.4727	.8292	.3250	.8826	2.160	.3712
$\frac{45}{64}$	.703125	.4944	.8385	.3476	.8892	2.209	.3883
$\frac{23}{32}$	.71875	.5166	.8478	.3713	.8958	2.258	.4057
$\frac{47}{64}$	.734375	.5393	.8569	.3961	.9022	2.307	.4236
$\frac{3}{4}$	.7500	.5625	.8660	.4219	.9086	2.356	.4418
$\frac{49}{64}$	.765625	.5862	.8750	.4488	.9148	2.405	.4604
$\frac{25}{32}$	.78125	.6104	.8839	.4768	.9210	2.454	.4794
$\frac{51}{64}$	.796875	.6350	.8927	.5060	.9271	2.503	.4987
$\frac{13}{16}$	.8125	.6602	.9014	.5364	.9331	2.553	.5185
$\frac{53}{64}$	.828125	.6858	.9100	.5679	.9391	2.602	.5386
$\frac{27}{32}$	.84375	.7119	.9186	.6007	.9449	2.651	.5592
$\frac{55}{64}$	.859375	.7385	.9270	.6347	.9507	2.700	.5801
$\frac{7}{8}$	.8750	.7656	.9354	.6699	.9565	2.749	.6013
$\frac{57}{64}$	.890625	.7932	.9437	.7064	.9621	2.798	.6230
$\frac{29}{32}$	.90625	.8213	.9520	.7443	.9677	2.847	.6450
$\frac{59}{64}$	.921875	.8499	.9601	.7835	.9732	2.896	.6675
$\frac{15}{16}$	.9375	.8789	.9682	.8240	.9787	2.945	.6903
$\frac{61}{64}$	.953125	.9084	.9763	.8659	.9841	2.994	.7135
$\frac{31}{32}$	.96875	.9385	.9843	.9091	.9895	3.043	.7371
$\frac{63}{64}$	.984375	.9690	.9922	.9539	.9948	3.093	.7610
1	1	1	1	1	1	3.1416	.7854

SQUARES, CUBES, SQUARE AND CUBE ROOTS OF NUMBERS FROM 1 TO 1000

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
1	1	1	1.0000	1.0000	51	2601	132651	7.1414	3.7084
2	4	8	1.4142	1.2599	52	2704	140608	7.2111	3.7325
3	9	27	1.7321	1.4422	53	2809	148877	7.2801	3.7563
4	16	64	2.0000	1.5874	54	2916	157464	7.3485	3.7798
5	25	125	2.2361	1.7100	55	3025	166375	7.4162	3.8030
6	36	216	2.4495	1.8171	56	3136	175616	7.4833	3.8259
7	49	343	2.6458	1.9129	57	3249	185193	7.5498	3.8485
8	64	512	2.8284	2.0000	58	3364	195112	7.6158	3.8709
9	81	729	3.0000	2.0801	59	3481	205379	7.6811	3.8930
10	100	1000	3.1623	2.1544	60	3600	216000	7.7460	3.9149
11	121	1331	3.3166	2.2240	61	3721	226981	7.8102	3.9365
12	144	1728	3.4641	2.2894	62	3844	238328	7.8740	3.9579
13	169	2197	3.6056	2.3513	63	3969	250047	7.9373	3.9791
14	196	2744	3.7417	2.4101	64	4096	262144	8.0000	4.0000
15	225	3375	3.8730	2.4662	65	4225	274625	8.0623	4.0207
16	256	4096	4.0000	2.5198	66	4356	287496	8.1240	4.0412
17	289	4913	4.1231	2.5713	67	4489	300763	8.1854	4.0615
18	324	5832	4.2426	2.6207	68	4624	314432	8.2462	4.0817
19	361	6859	4.3589	2.6684	69	4761	328509	8.3066	4.1016
20	400	8000	4.4721	2.7144	70	4900	343000	8.3666	4.1213
21	441	9261	4.5826	2.7589	71	5041	357911	8.4261	4.1408
22	484	10648	4.6904	2.8020	72	5184	373248	8.4853	4.1602
23	529	12167	4.7958	2.8439	73	5329	389017	8.5440	4.1793
24	576	13824	4.8990	2.8845	74	5476	405224	8.6023	4.1983
25	625	15625	5.0000	2.9240	75	5625	421875	8.6603	4.2172
26	676	17576	5.0990	2.9625	76	5776	438976	8.7178	4.2358
27	729	19683	5.1962	3.0000	77	5929	456533	8.7750	4.2543
28	784	21952	5.2915	3.0366	78	6084	474552	8.8318	4.2727
29	841	24389	5.3852	3.0723	79	6241	493039	8.8882	4.2908
30	900	27000	5.4772	3.1072	80	6400	512000	8.9443	4.3089
31	961	29791	5.5678	3.1414	81	6561	531441	9.0000	4.3267
32	1024	32768	5.6569	3.1748	82	6724	551368	9.0554	4.3445
33	1089	35937	5.7446	3.2075	83	6889	571787	9.1104	4.3621
34	1156	39304	5.8310	3.2396	84	7056	592704	9.1652	4.3795
35	1225	42875	5.9161	3.2711	85	7225	614125	9.2195	4.3968
36	1296	46656	6.0000	3.3019	86	7396	636056	9.2736	4.4140
37	1369	50653	6.0828	3.3322	87	7569	658503	9.3276	4.4310
38	1444	54872	6.1644	3.3620	88	7744	681472	9.3808	4.4480
39	1521	59319	6.2450	3.3912	89	7921	704969	9.4340	4.4647
40	1600	64000	6.3246	3.4200	90	8100	729000	9.4868	4.4814
41	1681	68921	6.4031	3.4482	91	8281	753571	9.5394	4.4979
42	1764	74088	6.4807	3.4760	92	8464	778688	9.5917	4.5144
43	1849	79507	6.5574	3.5034	93	8649	804357	9.6437	4.5307
44	1936	85184	6.6332	3.5303	94	8836	830584	9.6954	4.5468
45	2025	91125	6.7082	3.5569	95	9025	857375	9.7468	4.5629
46	2116	97336	6.7823	3.5830	96	9216	884736	9.7980	4.5789
47	2209	103823	6.8557	3.6088	97	9409	912673	9.8489	4.5947
48	2304	110592	6.9282	3.6342	98	9604	941192	9.8995	4.6104
49	2401	117649	7.0000	3.6593	99	9801	970299	9.9499	4.6261
50	2500	125000	7.0711	3.6840	100	10000	1000000	10.0000	4.6416

SQUARES, CUBES, SQUARE AND CUBE ROOTS OF NUMBERS FROM 1 TO 1000

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
101	10201	1030301	10.0499	4.6570	151	22801	3442951	12.2882	5.3251
102	10404	1061208	10.0995	4.6723	152	23104	3511808	12.3288	5.3368
103	10609	1092727	10.1489	4.6875	153	23409	3581577	12.3693	5.3485
104	10816	1124864	10.1980	4.7027	154	23716	3652264	12.4097	5.3601
105	11025	1157625	10.2470	4.7177	155	24025	3723875	12.4499	5.3717
106	11236	1191016	10.2956	4.7326	156	24336	3796416	12.4900	5.3832
107	11449	1225043	10.3441	4.7475	157	24649	3869893	12.5300	5.3947
108	11664	1259712	10.3923	4.7622	158	24964	3944312	12.5698	5.4061
109	11881	1295029	10.4403	4.7769	159	25281	4019679	12.6095	5.4175
110	12100	1331000	10.4881	4.7914	160	25600	4096000	12.6491	5.4288
111	12321	1367631	10.5357	4.8059	161	25921	4173281	12.6886	5.4401
112	12544	1404928	10.5830	4.8203	162	26244	4251528	12.7279	5.4514
113	12769	1442897	10.6301	4.8346	163	26569	4330747	12.7671	5.4626
114	12996	1481544	10.6771	4.8488	164	26896	4410944	12.8062	5.4737
115	13225	1520875	10.7238	4.8629	165	27225	4492125	12.8452	5.4848
116	13456	1560896	10.7703	4.8770	166	27556	4574296	12.8841	5.4959
117	13689	1601613	10.8167	4.8910	167	27889	4657463	12.9228	5.5069
118	13924	1643032	10.8628	4.9049	168	28224	4741632	12.9615	5.5178
119	14161	1685159	10.9087	4.9187	169	28561	4826809	13.0000	5.5288
120	14400	1728000	10.9545	4.9324	170	28900	4913000	13.0384	5.5397
121	14641	1771561	11.0000	4.9461	171	29241	5000211	13.0767	5.5505
122	14884	1815848	11.0454	4.9597	172	29584	5088448	13.1149	5.5613
123	15129	1860867	11.0905	4.9732	173	29929	5177717	13.1529	5.5721
124	15376	1906624	11.1355	4.9866	174	30276	5268024	13.1909	5.5828
125	15625	1953125	11.1803	5.0000	175	30625	5359375	13.2288	5.5934
126	15876	2000376	11.2250	5.0133	176	30976	5451776	13.2665	5.6041
127	16129	2048383	11.2694	5.0265	177	31329	5545233	13.3041	5.6147
128	16384	2097152	11.3137	5.0397	178	31684	5639752	13.3417	5.6252
129	16641	2146689	11.3578	5.0528	179	32041	5735339	13.3791	5.6357
130	16900	2197000	11.4018	5.0658	180	32400	5832000	13.4164	5.6462
131	17161	2248091	11.4455	5.0788	181	32761	5929741	13.4536	5.6567
132	17424	2299968	11.4891	5.0916	182	33124	6028568	13.4907	5.6671
133	17689	2352637	11.5326	5.1045	183	33489	6128487	13.5277	5.6774
134	17956	2406104	11.5758	5.1172	184	33856	6229504	13.5647	5.6877
135	18225	2460375	11.6190	5.1299	185	34225	6331625	13.6015	5.6980
136	18496	2515456	11.6619	5.1426	186	34596	6434856	13.6382	5.7083
137	18769	2571353	11.7047	5.1551	187	34969	6539203	13.6748	5.7185
138	19044	2628072	11.7473	5.1676	188	35344	6644672	13.7113	5.7287
139	19321	2685619	11.7898	5.1801	189	35721	6751269	13.7477	5.7388
140	19600	2744000	11.8322	5.1925	190	36100	6859000	13.7840	5.7489
141	19881	2803221	11.8743	5.2048	191	36481	6967871	13.8203	5.7590
142	20164	2863288	11.9164	5.2171	192	36864	7077888	13.8564	5.7690
143	20449	2924207	11.9583	5.2293	193	37249	7189057	13.8924	5.7790
144	20736	2985984	12.0000	5.2415	194	37636	7301384	13.9284	5.7890
145	21025	3048625	12.0416	5.2536	195	38025	7414875	13.9642	5.7989
146	21316	3112136	12.0830	5.2656	196	38416	7529536	14.0000	5.8088
147	21609	3176523	12.1244	5.2776	197	38809	7645373	14.0357	5.8186
148	21904	3241792	12.1655	5.2896	198	39204	7762392	14.0712	5.8285
149	22201	3307949	12.2066	5.3015	199	39601	7880599	14.1067	5.8383
150	22500	3375000	12.2474	5.3133	200	40000	8000000	14.1421	5.8480

SQUARES, CUBES, SQUARE AND CUBE ROOTS OF NUMBERS FROM 1 TO 1000

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
201	40401	8120601	14.1774	5.8578	251	63001	15813251	15.8430	6.3080
202	40804	8242408	14.2127	5.8675	252	63504	16003008	15.8745	6.3164
203	41209	8365427	14.2478	5.8771	253	64009	16194277	15.9060	6.3247
204	41616	8489664	14.2829	5.8868	254	64516	16387064	15.9374	6.3330
205	42025	8615125	14.3178	5.8964	255	65025	16581375	15.9687	6.3413
206	42436	8741816	14.3527	5.9059	256	65536	16777216	16.0000	6.3496
207	42849	8869743	14.3875	5.9155	257	66049	16974593	16.0312	6.3579
208	43264	8998912	14.4222	5.9250	258	66564	17173512	16.0624	6.3661
209	43681	9129329	14.4568	5.9345	259	67081	17373979	16.0935	6.3743
210	44100	9261000	14.4914	5.9439	260	67600	17576000	16.1245	6.3825
211	44521	9393931	14.5258	5.9533	261	68121	17779581	16.1555	6.3907
212	44944	9528128	14.5602	5.9627	262	68644	17984728	16.1864	6.3988
213	45369	9663597	14.5945	5.9721	263	69169	18191447	16.2173	6.4070
214	45796	9800344	14.6287	5.9814	264	69696	18399744	16.2481	6.4151
215	46225	9938375	14.6629	5.9907	265	70225	18609625	16.2788	6.4232
216	46656	10077696	14.6969	6.0000	266	70756	18821096	16.3095	6.4312
217	47089	10218313	14.7309	6.0092	267	71289	19034163	16.3401	6.4393
218	47524	10360232	14.7648	6.0185	268	71824	19248832	16.3707	6.4473
219	47961	10503459	14.7986	6.0277	269	72361	19465109	16.4012	6.4553
220	48400	10648000	14.8324	6.0368	270	72900	19683000	16.4317	6.4633
221	48841	10793861	14.8661	6.0459	271	73441	19902511	16.4621	6.4713
222	49284	10941048	14.8997	6.0550	272	73984	20123648	16.4924	6.4792
223	49729	11089567	14.9332	6.0641	273	74529	20346417	16.5227	6.4872
224	50176	11239424	14.9666	6.0732	274	75076	20570824	16.5529	6.4951
225	50625	11390625	15.0000	6.0822	275	75625	20796875	16.5831	6.5030
226	51076	11543176	15.0333	6.0912	276	76176	21024576	16.6132	6.5108
227	51529	11697083	15.0665	6.1002	277	76729	21253933	16.6433	6.5187
228	51984	11852352	15.0997	6.1091	278	77284	21484952	16.6733	6.5265
229	52441	12008989	15.1327	6.1180	279	77841	21717639	16.7033	6.5343
230	52900	12167000	15.1658	6.1269	280	78400	21952000	16.7332	6.5421
231	53361	12326391	15.1987	6.1358	281	78961	22188041	16.7631	6.5499
232	53824	12487168	15.2315	6.1446	282	79524	22425768	16.7929	6.5577
233	54289	12649337	15.2643	6.1534	283	80089	22665187	16.8226	6.5654
234	54756	12812904	15.2971	6.1622	284	80656	22906304	16.8523	6.5731
235	55225	12977875	15.3297	6.1710	285	81225	23149125	16.8819	6.5808
236	55696	13144256	15.3623	6.1797	286	81796	23393656	16.9115	6.5885
237	56169	13312053	15.3948	6.1885	287	82369	23639903	16.9411	6.5962
238	56644	13481272	15.4272	6.1972	288	82944	23887872	16.9706	6.6039
239	57121	13651919	15.4596	6.2058	289	83521	24137569	17.0000	6.6115
240	57600	13824000	15.4919	6.2145	290	84100	24389000	17.0294	6.6191
241	58081	13997521	15.5242	6.2231	291	84681	24642171	17.0587	6.6267
242	58564	14172488	15.5563	6.2317	292	85264	24897088	17.0880	6.6343
243	59049	14348907	15.5885	6.2403	293	85849	25153757	17.1172	6.6419
244	59536	14526784	15.6205	6.2488	294	86436	25412184	17.1464	6.6494
245	60025	14706125	15.6525	6.2573	295	87025	25672375	17.1756	6.6569
246	60516	14886936	15.6844	6.2658	296	87616	25934336	17.2047	6.6644
247	61009	15069223	15.7162	6.2743	297	88209	26198073	17.2337	6.6719
248	61504	15252992	15.7480	6.2828	298	88804	26463592	17.2627	6.6794
249	62001	15438249	15.7797	6.2012	299	89401	26730899	17.2916	6.6869
250	62500	15625000	15.8114	6.2996	300	90000	27000000	17.3205	6.6943

SQUARES, CUBES, SQUARE AND CUBE ROOTS OF NUMBERS FROM 1 TO 1000

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
301	90601	27270901	17.3494	6.7018	351	123201	43243551	18.7350	7.0540
302	91204	27543608	17.3781	6.7092	352	123904	43614208	18.7617	7.0607
303	91809	27818127	17.4069	6.7166	353	124609	43986977	18.7883	7.0674
304	92416	28094464	17.4356	6.7240	354	125316	44361864	18.8149	7.0740
305	93025	28372625	17.4642	6.7313	355	126025	44738875	18.8414	7.0807
306	93636	28652616	17.4929	6.7387	356	126736	45118016	18.8680	7.0873
307	94249	28934443	17.5214	6.7460	357	127449	45499293	18.8944	7.0940
308	94864	29218112	17.5499	6.7533	358	128164	45882712	18.9209	7.1006
309	95481	29503629	17.5784	6.7606	359	128881	46268279	18.9473	7.1072
310	96100	29791000	17.6068	6.7679	360	129600	46656000	18.9737	7.1138
311	96721	30080231	17.6352	6.7752	361	130321	47045881	19.0000	7.1204
312	97344	30371328	17.6635	6.7824	362	131044	47437928	19.0263	7.1269
313	97969	30664297	17.6918	6.7897	363	131769	47832147	19.0526	7.1335
314	98596	30959144	17.7200	6.7969	364	132496	48228544	19.0788	7.1400
315	99225	31255875	17.7482	6.8041	365	133225	48627125	19.1050	7.1466
316	99856	31554496	17.7764	6.8113	366	133956	49027896	19.1311	7.1531
317	100489	31855013	17.8045	6.8185	367	134689	49430863	19.1572	7.1596
318	101124	32157432	17.8326	6.8256	368	135424	49836032	19.1833	7.1661
319	101761	32461759	17.8606	6.8328	369	136161	50243409	19.2094	7.1726
320	102400	32768000	17.8885	6.8399	370	136900	50653000	19.2354	7.1791
321	103041	33076161	17.9165	6.8470	371	137641	51064811	19.2614	7.1855
322	103684	33386248	17.9444	6.8541	372	138384	51478848	19.2873	7.1920
323	104329	33698267	17.9722	6.8612	373	139129	51895117	19.3132	7.1984
324	104976	34012224	18.0000	6.8683	374	139876	52313624	19.3391	7.2048
325	105625	34328125	18.0278	6.8753	375	140625	52734375	19.3649	7.2112
326	106276	34645976	18.0555	6.8824	376	141376	53157376	19.3907	7.2177
327	106929	34965783	18.0831	6.8894	377	142129	53582633	19.4165	7.2240
328	107584	35287552	18.1108	6.8964	378	142884	54010152	19.4422	7.2304
329	108241	35611289	18.1384	6.9034	379	143641	54439939	19.4679	7.2368
330	108900	35937000	18.1659	6.9104	380	144400	54872000	19.4936	7.2432
331	109561	36264691	18.1934	6.9174	381	145161	55306341	19.5192	7.2495
332	110224	36594368	18.2209	6.9244	382	145924	55742968	19.5448	7.2558
333	110889	36926037	18.2483	6.9313	383	146689	56181887	19.5704	7.2622
334	111556	37259704	18.2757	6.9382	384	147456	56623104	19.5959	7.2685
335	112225	37595375	18.3030	6.9451	385	148225	57066625	19.6214	7.2748
336	112896	37933056	18.3303	6.9521	386	148996	57512456	19.6469	7.2811
337	113569	38272753	18.3576	6.9589	387	149769	57960603	19.6723	7.2874
338	114244	38614472	18.3848	6.9658	388	150544	58411072	19.6977	7.2936
339	114921	38958219	18.4120	6.9727	389	151321	58863869	19.7231	7.2999
340	115600	39304000	18.4391	6.9795	390	152100	59319000	19.7484	7.3061
341	116281	39651821	18.4662	6.9864	391	152881	59776471	19.7737	7.3124
342	116964	40001688	18.4932	6.9932	392	153664	60236288	19.7990	7.3186
343	117649	40353607	18.5203	7.0000	393	154449	60698457	19.8242	7.3248
344	118336	40707584	18.5472	7.0068	394	155236	61162984	19.8494	7.3310
345	119025	41063625	18.5742	7.0136	395	156025	61629875	19.8746	7.3372
346	119716	41421736	18.6011	7.0203	396	156816	62099136	19.8997	7.3434
347	120409	41781923	18.6279	7.0271	397	157609	62570773	19.9249	7.3496
348	121104	42144192	18.6548	7.0338	398	158404	63044792	19.9499	7.3558
349	121801	42508549	18.6815	7.0406	399	159201	63521199	19.9750	7.3619
350	122500	42875000	18.7083	7.0473	400	160000	64000000	20.0000	7.3681

SQUARES, CUBES, SQUARE AND CUBE ROOTS OF NUMBERS FROM 1 TO 1000

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
401	160801	64481201	20.0250	7.3742	451	203401	91733851	21.2368	7.6688
402	161604	64964808	20.0499	7.3803	452	204304	92345408	21.2603	7.6744
403	162409	65450827	20.0749	7.3864	453	205209	92959677	21.2838	7.6800
404	163216	65939264	20.0998	7.3925	454	206116	93576664	21.3073	7.6857
405	164025	66430125	20.1246	7.3986	455	207025	94196375	21.3307	7.6914
406	164836	66923416	20.1494	7.4047	456	207936	94818816	21.3542	7.6970
407	165649	67419143	20.1742	7.4108	457	208849	95443993	21.3776	7.7026
408	166464	67917312	20.1990	7.4169	458	209764	96071912	21.4009	7.7082
409	167281	68417929	20.2237	7.4229	459	210681	96702579	21.4243	7.7138
410	168100	68921000	20.2485	7.4290	460	211600	97336000	21.4476	7.7194
411	168921	69426531	20.2731	7.4350	461	212521	97972181	21.4709	7.7250
412	169744	69934528	20.2978	7.4410	462	213444	98611128	21.4942	7.7306
413	170569	70444997	20.3224	7.4470	463	214369	99252847	21.5174	7.7362
414	171396	70957944	20.3470	7.4530	464	215296	99897344	21.5407	7.7418
415	172225	71473375	20.3715	7.4590	465	216225	100544625	21.5639	7.7473
416	173056	71991296	20.3961	7.4650	466	217156	101194696	21.5870	7.7529
417	173889	72511713	20.4206	7.4710	467	218089	101847563	21.6102	7.7584
418	174724	73034632	20.4450	7.4770	468	219024	102503232	21.6333	7.7639
419	175561	73560059	20.4695	7.4829	469	219961	103161709	21.6564	7.7695
420	176400	74088000	20.4939	7.4889	470	220900	103823000	21.6795	7.7750
421	177241	74618461	20.5183	7.4948	471	221841	104487111	21.7025	7.7805
422	178084	75151448	20.5426	7.5007	472	222784	105154048	21.7256	7.7860
423	178929	75686967	20.5670	7.5067	473	223729	105823817	21.7486	7.7915
424	179776	76225024	20.5913	7.5126	474	224676	106496424	21.7715	7.7970
425	180625	76765625	20.6155	7.5185	475	225625	107171875	21.7945	7.8025
426	181476	77308776	20.6398	7.5244	476	226576	107850176	21.8174	7.8079
427	182329	77854483	20.6640	7.5302	477	227529	108531333	21.8403	7.8134
428	183184	78402752	20.6882	7.5361	478	228484	109215352	21.8632	7.8188
429	184041	78953589	20.7123	7.5420	479	229441	109902239	21.8861	7.8243
430	184900	79507000	20.7364	7.5478	480	230400	110592000	21.9089	7.8297
431	185761	80062991	20.7605	7.5537	481	231361	111284641	21.9317	7.8352
432	186624	80621568	20.7846	7.5595	482	232324	111980168	21.9545	7.8406
433	187489	81182737	20.8087	7.5654	483	233289	112678587	21.9773	7.8460
434	188356	81746504	20.8327	7.5712	484	234256	113379904	22.0000	7.8514
435	189225	82312875	20.8567	7.5770	485	235225	114084125	22.0227	7.8568
436	190096	82881856	20.8806	7.5828	486	236196	114791256	22.0454	7.8622
437	190969	83453453	20.9045	7.5886	487	237169	115501303	22.0681	7.8676
438	191844	84027672	20.9284	7.5944	488	238144	116214272	22.0907	7.8730
439	192721	84604519	20.9523	7.6001	489	239121	116930169	22.1133	7.8784
440	193600	85184000	20.9762	7.6059	490	240100	117649000	22.1359	7.8837
441	194481	85766121	21.0000	7.6117	491	241081	118370771	22.1585	7.8891
442	195364	86350888	21.0238	7.6174	492	242064	119095488	22.1811	7.8944
443	196249	86938307	21.0476	7.6232	493	243049	119823157	22.2036	7.8998
444	197136	87528384	21.0713	7.6289	494	244036	120553784	22.2261	7.9051
445	198025	88121125	21.0950	7.6346	495	245025	121287375	22.2486	7.9105
446	198916	88716536	21.1187	7.6403	496	246016	122023936	22.2711	7.9158
447	199809	89314623	21.1424	7.6460	497	247009	122763473	22.2935	7.9211
448	200704	89915392	21.1660	7.6517	498	248004	123505992	22.3159	7.9264
449	201601	90518849	21.1896	7.6574	499	249001	124251499	22.3383	7.9317
450	202500	91125000	21.2132	7.6631	500	250000	125000000	22.3607	7.9370

SQUARES, CUBES, SQUARE AND CUBE ROOTS OF NUMBERS FROM 1 TO 1000

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
501	251001	125751501	22.3830	7.9423	551	303601	167284151	23.4734	8.1982
502	252004	126506008	22.4054	7.9476	552	304704	168196608	23.4947	8.2031
503	253009	127263527	22.4277	7.9528	553	305809	169112377	23.5160	8.2081
504	254016	128024064	22.4499	7.9581	554	306916	170031464	23.5372	8.2130
505	255025	128787625	22.4722	7.9634	555	308025	170953875	23.5584	8.2180
506	256036	129554216	22.4944	7.9686	556	309136	171879616	23.5797	8.2229
507	257049	130323843	22.5167	7.9739	557	310249	172808693	23.6008	8.2278
508	258064	131096512	22.5389	7.9791	558	311364	173741112	23.6220	8.2327
509	259081	131872229	22.5610	7.9843	559	312481	174676879	23.6432	8.2377
510	260100	132651000	22.5832	7.9896	560	313600	175616000	23.6643	8.2426
511	261121	133432831	22.6053	7.9948	561	314721	176558481	23.6854	8.2475
512	262144	134217728	22.6274	8.0000	562	315844	177504328	23.7065	8.2524
513	263169	135005697	22.6495	8.0052	563	316969	178453547	23.7276	8.2573
514	264196	135796744	22.6716	8.0104	564	318096	179406144	23.7487	8.2621
515	265225	136590875	22.6936	8.0156	565	319225	180362125	23.7697	8.2670
516	266256	137388096	22.7156	8.0208	566	320356	181321496	23.7908	8.2719
517	267289	138188413	22.7376	8.0260	567	321489	182284263	23.8118	8.2768
518	268324	138991832	22.7596	8.0311	568	322624	183250432	23.8328	8.2816
519	269361	139798359	22.7816	8.0363	569	323761	184220009	23.8537	8.2865
520	270400	140608000	22.8035	8.0415	570	324900	185193000	23.8747	8.2913
521	271441	141420761	22.8254	8.0466	571	326041	186169411	23.8956	8.2962
522	272484	142236648	22.8473	8.0517	572	327184	187149248	23.9165	8.3010
523	273529	143055667	22.8692	8.0569	573	328329	188132517	23.9374	8.3059
524	274576	143877824	22.8910	8.0620	574	329476	189119224	23.9583	8.3107
525	275625	144703125	22.9129	8.0671	575	330625	190109375	23.9792	8.3155
526	276676	145531576	22.9347	8.0723	576	331776	191102976	24.0000	8.3203
527	277729	146363183	22.9565	8.0774	577	332929	192100033	24.0208	8.3251
528	278784	147197952	22.9783	8.0825	578	334084	193100552	24.0416	8.3300
529	279841	148035889	23.0000	8.0876	579	335241	194104539	24.0624	8.3348
530	280900	148877000	23.0217	8.0927	580	336400	195112000	24.0832	8.3396
531	281961	149721291	23.0434	8.0978	581	337561	196122941	24.1039	8.3443
532	283024	150568768	23.0651	8.1028	582	338724	197137368	24.1247	8.3491
533	284089	151419437	23.0868	8.1079	583	339889	198155287	24.1454	8.3539
534	285156	152273304	23.1084	8.1130	584	341056	199176704	24.1661	8.3587
535	286225	153130375	23.1301	8.1180	585	342225	200201625	24.1868	8.3634
536	287296	153990656	23.1517	8.1231	586	343396	201230056	24.2074	8.3682
537	288369	154854153	23.1733	8.1281	587	344569	202262003	24.2281	8.3730
538	289444	155720872	23.1948	8.1332	588	345744	203297472	24.2487	8.3777
539	290521	156590819	23.2164	8.1382	589	346921	204336469	24.2693	8.3825
540	291600	157464000	23.2379	8.1433	590	348100	205379000	24.2899	8.3872
541	292681	158340421	23.2594	8.1483	591	349281	206425071	24.3105	8.3919
542	293764	159220088	23.2809	8.1533	592	350464	207474688	24.3311	8.3967
543	294849	160103007	23.3024	8.1583	593	351649	208527857	24.3516	8.4014
544	295936	160989184	23.3238	8.1633	594	352836	209584584	24.3721	8.4061
545	297025	161878625	23.3452	8.1683	595	354025	210644875	24.3926	8.4108
546	298116	162771336	23.3666	8.1733	596	355216	211708736	24.4131	8.4155
547	299209	163667323	23.3880	8.1783	597	356409	212776173	24.4336	8.4202
548	300304	164566592	23.4094	8.1833	598	357604	213847192	24.4540	8.4249
549	301401	165469149	23.4307	8.1882	599	358801	214921799	24.4715	8.4296
550	302500	166375000	23.4521	8.1932	600	360000	216000000	24.4949	8.4343

Squares, Cubes, Square and Cube Roots of Numbers from 1 to 1000

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
601	361201	217081801	24.5153	8.4390	651	423801	275894451	25.5147	8.6668
602	362404	218167208	24.5357	8.4437	652	425104	277167808	25.5343	8.6713
603	363609	219256227	24.5561	8.4484	653	426409	278445077	25.5539	8.6757
604	364816	220348864	24.5764	8.4530	654	427716	279726264	25.5734	8.6801
605	366025	221445125	24.5967	8.4577	655	429025	281011375	25.5930	8.6845
606	367236	222545016	24.6171	8.4623	656	430336	282300416	25.6125	8.6890
607	368449	223648543	24.6374	8.4670	657	431649	283593393	25.6320	8.6934
608	369664	224755712	24.6577	8.4716	658	432964	284890312	25.6515	8.6978
609	370881	225866529	24.6779	8.4763	659	434281	286191179	25.6710	8.7022
610	372100	226981000	24.6982	8.4809	660	435600	287496000	25.6905	8.7066
611	373321	228099131	24.7184	8.4856	661	436921	288804781	25.7099	8.7110
612	374544	229220928	24.7386	8.4902	662	438244	290117528	25.7294	8.7154
613	375769	230346397	24.7588	8.4948	663	439569	291434247	25.7488	8.7198
614	376996	231475544	24.7790	8.4994	664	440896	292754944	25.7682	8.7241
615	378225	232608375	24.7992	8.5040	665	442225	294079625	25.7876	8.7285
616	379456	233744896	24.8193	8.5086	666	443556	295408296	25.8070	8.7329
617	380689	234885113	24.8395	8.5132	667	444889	296740963	25.8263	8.7373
618	381924	236029032	24.8596	8.5178	668	446224	298077632	25.8457	8.7416
619	383161	237176659	24.8797	8.5224	669	447561	299418309	25.8650	8.7460
620	384400	238328000	24.8998	8.5270	670	448900	300763000	25.8844	8.7503
621	385641	239483061	24.9199	8.5316	671	450241	302111711	25.9037	8.7547
622	386884	240641848	24.9399	8.5362	672	451584	303464448	25.9230	8.7590
623	388129	241804367	24.9600	8.5408	673	452929	304821217	25.9422	8.7634
624	389376	242970624	24.9800	8.5453	674	454276	306182024	25.9615	8.7677
625	390625	244140625	25.0000	8.5499	675	455625	307546875	25.9808	8.7721
626	391876	245314376	25.0200	8.5544	676	456976	308915776	26.0000	8.7764
627	393129	246491883	25.0400	8.5590	677	458329	310288733	26.0192	8.7807
628	394384	247673152	25.0599	8.5635	678	459684	311665752	26.0384	8.7850
629	395641	248858189	25.0799	8.5681	679	461041	313046839	26.0576	8.7893
630	396900	250047000	25.0998	8.5726	680	462400	314432000	26.0768	8.7937
631	398161	251239591	25.1197	8.5772	681	463761	315821241	26.0960	8.7980
632	399424	252435968	25.1396	8.5817	682	465124	317214568	26.1151	8.8023
633	400689	253636137	25.1595	8.5862	683	466489	318611987	26.1343	8.8066
634	401956	254840104	25.1794	8.5907	684	467856	320013504	26.1534	8.8109
635	403225	256047875	25.1992	8.5952	685	469225	321419125	26.1725	8.8152
636	404496	257259456	25.2190	8.5997	686	470596	322828856	26.1916	8.8194
637	405769	258474853	25.2389	8.6043	687	471969	324242703	26.2107	8.8237
638	407044	259694072	25.2587	8.6088	688	473344	325660672	26.2298	8.8280
639	408321	260917119	25.2784	8.6132	689	474721	327082769	26.2488	8.8323
640	409600	262144000	25.2982	8.6177	690	476100	328509000	26.2679	8.8366
641	410881	263374721	25.3180	8.6222	691	477481	329939371	26.2869	8.8408
642	412164	264609288	25.3377	8.6267	692	478864	331373888	26.3059	8.8451
643	413449	265847707	25.3574	8.6312	693	480249	332812557	26.3249	8.8493
644	414736	267089984	25.3772	8.6357	694	481636	334255384	26.3439	8.8536
645	416025	268336125	25.3969	8.6401	695	483025	335702375	26.3629	8.8578
646	417316	269586136	25.4165	8.6446	696	484416	337153536	26.3818	8.8621
647	418609	270840023	25.4362	8.6490	697	485809	338608873	26.4008	8.8663
648	419904	272097792	25.4558	8.6535	698	487204	340068392	26.4197	8.8706
649	421201	273359449	25.4755	8.6579	699	488601	341532099	26.4386	8.8748
650	422500	274625000	25.4951	8.6624	700	490000	343000000	26.4575	8.8790

SQUARES, CUBES, SQUARE AND CUBE ROOTS OF NUMBERS FROM 1 TO 1000

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
701	491401	344472101	26.4764	8.8833	751	564001	423564751	27.4044	9.0896
702	492804	345948408	26.4953	8.8875	752	565504	425259008	27.4226	9.0937
703	494209	347428927	26.5141	8.8917	753	567009	426957777	27.4408	9.0977
704	495616	348913664	26.5330	8.8959	754	568516	428661064	27.4591	9.1017
705	497025	350402625	26.5518	8.9001	755	570025	430368875	27.4773	9.1057
706	498436	351895816	26.5707	8.9043	756	571536	432081216	27.4955	9.1098
707	499849	353393243	26.5895	8.9085	757	573049	433798093	27.5136	9.1138
708	501264	354894912	26.6083	8.9127	758	574564	435519512	27.5318	9.1178
709	502681	356400829	26.6271	8.9169	759	576081	437245479	27.5500	9.1218
710	504100	357911000	26.6458	8.9211	760	577600	438976000	27.5681	9.1258
711	505521	359425431	26.6646	8.9253	761	579121	440711081	27.5862	9.1298
712	506944	360944128	26.6833	8.9295	762	580644	442450728	27.6043	9.1338
713	508369	362467097	26.7021	8.9337	763	582169	444194947	27.6225	9.1378
714	509796	363994344	26.7208	8.9378	764	583696	445943744	27.6405	9.1418
715	511225	365525875	26.7395	8.9420	765	585225	447697125	27.6586	9.1458
716	512656	367061696	26.7582	8.9462	766	586756	449455096	27.6767	9.1498
717	514089	368601813	26.7769	8.9503	767	588289	451217663	27.6948	9.1537
718	515524	370146232	26.7955	8.9545	768	589824	452984832	27.7128	9.1577
719	516961	371694959	26.8142	8.9587	769	591361	454756609	27.7308	9.1617
720	518400	373248000	26.8328	8.9628	770	592900	456533000	27.7489	9.1657
721	519841	374805361	26.8514	8.9670	771	594441	458314011	27.7669	9.1696
722	521284	376367048	26.8701	8.9711	772	595984	460099648	27.7849	9.1736
723	522729	377933067	26.8887	8.9752	773	597529	461889917	27.8029	9.1775
724	524176	379503424	26.9072	8.9794	774	599076	463684824	27.8209	9.1815
725	525625	381078125	26.9258	8.9835	775	600625	465484375	27.8388	9.1855
726	527076	382657176	26.9444	8.9876	776	602176	467288576	27.8568	9.1894
727	528529	384240583	26.9629	8.9918	777	603729	469097433	27.8747	9.1933
728	529984	385828352	26.9815	8.9959	778	605284	470910952	27.8927	9.1973
729	531441	387420489	27.0000	9.0000	779	606841	472729139	27.9106	9.2012
730	532900	389017000	27.0185	9.0041	780	608400	474552000	27.9285	9.2052
731	534361	390617891	27.0370	9.0082	781	609961	476379541	27.9464	9.2091
732	535824	392223168	27.0555	9.0123	782	611524	478211768	27.9643	9.2130
733	537289	393832837	27.0740	9.0164	783	613089	480048687	27.9821	9.2170
784	538756	395446904	27.0924	9.0205	784	614656	481890304	28.0000	9.2209
735	540225	397065375	27.1109	9.0246	785	616225	483736625	28.0179	9.2248
736	541696	398688256	27.1293	9.0287	786	617796	485587656	28.0357	9.2287
737	543169	400315553	27.1477	9.0328	787	619369	487443403	28.0535	9.2326
738	544644	401947272	27.1662	9.0369	788	620944	489303872	28.0713	9.2365
739	546121	403583419	27.1846	9.0410	789	622521	491169069	28.0891	9.2404
740	547600	405224000	27.2029	9.0450	790	624100	493039000	28.1069	9.2443
741	549081	406869021	27.2213	9.0491	791	625681	494913671	28.1247	9.2482
742	550564	408518488	27.2397	9.0532	792	627264	496793088	28.1425	9.2521
743	552049	410172407	27.2580	9.0572	703	628849	498677257	28.1603	9.2560
744	553536	411830784	27.2764	9.0613	794	630436	500566184	28.1780	9.2599
745	555025	413493625	27.2947	9.0654	795	632025	502459875	28.1957	9.2638
746	556516	415160936	27.3130	9.0694	796	633616	504358336	28.2135	9.2677
747	558009	416832723	27.3313	9.0735	797	635209	506261573	28.2312	9.2716
748	559504	418508992	27.3496	9.0775	798	636804	508160592	28.2489	9.2754
749	561001	420189749	27.3670	9.0816	799	638401	510082399	28.2666	9.2793
750	562500	421875000	27.3861	9.0856	800	640000	512000000	28.2843	9.2832

Squares, Cubes, Square and Cube Roots of Numbers from 1 to 1000

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
801	641601	513922401	28.3019	9.2870	851	724201	616295051	29.1719	9.4764
802	643204	515849608	28.3196	9.2909	852	725904	618470208	29.1890	9.4801
803	644809	517781627	28.3373	9.2948	853	727609	620650477	29.2062	9.4838
804	646416	519718464	28.3549	9.2986	854	729316	622835864	29.2233	9.4875
805	648025	521660125	28.3725	9.3025	855	731025	625026375	29.2404	9.4912
806	649636	523606616	28.3901	9.3063	856	732736	627222016	29.2575	9.4949
807	651249	525557943	28.4077	9.3102	857	734449	629422793	29.2746	9.4986
808	652864	527514112	28.4253	9.3140	858	736164	631628712	29.2916	9.5023
809	654481	529475129	28.4429	9.3179	859	737881	633839779	29.3087	9.5060
810	656100	531441000	28.4605	9.3217	860	739600	636056000	29.3258	9.5097
811	657721	533411731	28.4781	9.3255	861	741321	638277381	29.3428	9.5134
812	659344	535387328	28.4956	9.3294	862	743044	640503928	29.3598	9.5171
813	660969	537367797	28.5132	9.3332	863	744769	642735647	29.3769	9.5207
814	662596	539353144	28.5307	9.3370	864	746496	644972544	29.3939	9.5244
815	664225	541343375	28.5482	9.3408	865	748225	647214625	29.4109	9.5281
816	665856	543338496	28.5657	9.3447	866	749956	649461896	29.4279	9.5317
817	667489	545338513	28.5832	9.3485	867	751689	651714363	29.4449	9.5354
818	669124	547343432	28.6007	9.3523	868	753424	653972032	29.4618	9.5391
819	670761	549353259	28.6182	9.3561	869	755161	656234909	29.4788	9.5427
820	672400	551368000	28.6356	9.3599	870	756900	658503000	29.4958	9.5464
821	674041	553387661	28.6531	9.3637	871	758641	660776311	29.5127	9.5501
822	675684	555412248	28.6705	9.3675	872	760384	663054848	29.5296	9.5537
823	677329	557441767	28.6880	9.3713	873	762129	665338617	29.5466	9.5574
824	678976	559476224	28.7054	9.3751	874	763876	667627624	29.5635	9.5610
825	680625	561515625	28.7228	9.3789	875	765625	669921875	29.5804	9.5647
826	682276	563559976	28.7402	9.3827	876	767376	672221376	29.5973	9.5683
827	683929	565609283	28.7576	9.3865	877	769129	674526133	29.6142	9.5719
828	685584	567663552	28.7750	9.3902	878	770884	676836152	29.6311	9.5756
829	687241	569722789	28.7924	9.3940	879	772641	679151439	29.6479	9.5792
830	688900	571787000	28.8097	9.3978	880	774400	681472000	29.6648	9.5828
831	690561	573856191	28.8271	9.4016	881	776161	683797841	29.6816	9.5865
832	692224	575930368	28.8444	9.4053	882	777924	686128968	29.6985	9.5901
833	693889	578009537	28.8617	9.4091	883	779689	688465387	29.7153	9.5937
834	695556	580093704	28.8791	9.4129	884	781456	690807104	29.7321	9.5973
835	697225	582182875	28.8964	9.4166	885	783225	693154125	29.7489	9.6010
836	698896	584277056	28.9137	9.4204	886	784996	695506456	29.7658	9.6046
837	700569	586376253	28.9310	9.4241	887	786769	697864103	29.7825	9.6082
838	702244	588480472	28.9482	9.4279	888	788544	700227072	29.7993	9.6118
839	703921	590589719	28.9655	9.4316	889	790321	702595369	29.8161	9.6154
840	705600	592704000	28.9828	9.4354	890	792100	704969000	29.8329	9.6190
841	707281	594823321	29.0000	9.4391	891	793881	707347971	29.8496	9.6226
842	708964	596947688	29.0172	9.4429	892	795664	709732288	29.8664	9.6262
843	710649	599077107	29.0345	9.4466	893	797449	712121957	29.8831	9.6298
844	712336	601211584	29.0517	9.4503	894	799236	714516984	29.8998	9.6334
845	714025	603351125	29.0689	9.4541	895	801025	716917375	29.9166	9.6370
846	715716	605495736	29.0861	9.4578	896	802816	719323136	29.9333	9.6406
847	717409	607645423	29.1033	9.4615	897	804609	721734273	20.9500	9.6442
848	719104	609800192	29.1204	9.4652	898	806404	724150792	29.9666	9.6477
849	720801	611960049	29.1376	9.4690	899	808201	726572699	29.9833	9.6513
850	722500	614125000	29.1548	9.4727	900	810000	729000000	30.0000	9.6549

SQUARES, CUBES, SQUARE AND CUBE ROOTS OF NUMBERS FROM 1 TO 1000

No.	Square	Cube	Sq. Root	Cube Root	No.	Square	Cube	Sq. Root	Cube Root
901	811801	731432701	30.0167	9.6585	951	904401	860085351	30.8383	9.8339
902	813604	733870808	30.0333	9.6620	952	906304	862801408	30.8545	9.8374
903	815409	736314327	30.0500	9.6656	953	908209	865523177	30.8707	9.8408
904	817216	738763264	30.0666	9.6692	954	910116	868250664	30.8869	9.8443
905	819025	741217625	30.0832	9.6727	955	912025	870983875	30.9031	9.8477
906	820836	743677416	30.0998	9.6763	956	913936	873722816	30.9192	9.8511
907	822649	746142643	30.1164	9.6799	957	915849	876467493	30.9354	9.8546
908	824464	748613312	30.1330	9.6834	958	917764	879217912	30.9516	9.8580
909	826281	751089429	30.1496	9.6870	959	919681	881974079	30.9677	9.8614
910	828100	753571000	30.1662	9.6905	960	921600	884736000	30.9839	9.8648
911	829921	756058031	30.1828	9.6941	961	923521	887503681	31.0000	9.8683
912	831744	758550528	30.1993	9.6976	962	925444	890277128	31.0161	9.8717
913	833569	761048497	30.2159	9.7012	963	927369	893056347	31.0322	9.8751
914	835396	763551944	30.2324	9.7047	964	929296	895841344	31.0483	9.8785
915	837225	766060875	30.2490	9.7082	965	931225	898632125	31.0644	9.8819
916	839056	768575296	30.2655	9.7118	966	933156	901428696	31.0805	9.8854
917	840889	771095213	30.2820	9.7153	967	935089	904231063	31.0966	9.8888
918	842724	773620632	30.2985	9.7188	968	937024	907039232	31.1127	9.8922
919	844561	776151559	30.3150	9.7224	969	938961	909853209	31.1288	9.8956
920	846400	778688000	30.3315	9.7259	970	940900	912673000	31.1448	9.8990
921	848241	781229961	30.3480	9.7294	971	942841	915498611	31.1609	9.9024
922	850084	783777448	30.3645	9.7329	972	944784	918330048	31.1769	9.9058
923	851929	786330467	30.3809	9.7364	973	946729	921167317	31.1929	9.9092
924	853776	788889024	30.3974	9.7400	974	948676	924010424	31.2090	9.9126
925	855625	791453125	30.4138	9.7435	975	950625	926859375	31.2250	9.9160
926	857476	794022776	30.4302	9.7470	976	952576	929714176	31.2410	9.9194
927	859329	796597983	30.4467	9.7505	977	954529	932574833	31.2570	9.9227
928	861184	799178752	30.4631	9.7540	978	956484	935441352	31.2730	9.9261
929	863041	801765089	30.4795	9.7575	979	958441	938313739	31.2890	9.9295
930	864900	804357000	30.4959	9.7610	980	960400	941192000	31.3050	9.9329
931	866761	806954491	30.5123	9.7645	981	962361	944076141	31.3209	9.9363
932	868624	809557568	30.5287	9.7680	982	964324	946966168	31.3369	9.9396
933	870489	812166237	30.5450	9.7715	983	966289	949862087	31.3528	9.9430
934	872356	814780504	30.5614	9.7750	984	968256	952763904	31.3688	9.9464
935	874225	817400375	30.5778	9.7785	985	970225	955671625	31.3847	9.9497
936	876096	820025856	30.5941	9.7819	986	972196	958585256	31.4006	9.9531
937	877969	822656953	30.6105	9.7854	987	974169	961504803	31.4166	9.9565
938	879844	825293672	30.6268	9.7889	988	976144	964430272	31.4325	9.9598
939	881721	827936019	30.6431	9.7924	989	978121	967361669	31.4484	9.9632
940	883600	830584000	30.6594	9.7959	990	980100	970299000	31.4643	9.9666
941	885481	833237621	30.6757	9.7993	991	982081	973242271	31.4802	9.9699
942	887364	835896888	30.6920	9.8028	992	984064	976191488	31.4960	9.9733
943	889249	838561807	30.7083	9.8063	993	986049	979146657	31.5119	9.9766
944	891136	841232384	30.7246	9.8097	994	988036	982107784	31.5278	9.9800
945	893025	843908625	30.7409	9.8132	995	990025	985074875	31.5436	9.9833
946	894916	846590536	30.7571	9.8167	996	992016	988047936	31.5595	9.9866
947	896809	849278123	30.7734	9.8201	997	994009	991026973	31.5753	9.9900
948	898704	851971392	30.7896	9.8236	998	996004	994011992	31.5911	9.9933
949	900601	854670349	30.8058	9.8270	999	998001	997002999	31.6070	9.9967
950	902500	857375000	30.8221	9.8305	1000	1000000	1000000000	31.6228	10.0000

Areas and Circumferences of Circles from 1 to 100

Dia.	Area	Circum.	Dia.	Area	Circum.	Dia.	Area	Circum.
1/32	0.00077	0.098175	2	3.1416	6.28319	5	19.635	15.7080
3/64	0.00173	0.147262	1/16	3.3410	6.47953	1/16	20.129	15.9043
1/16	0.00307	0.196350	1/8	3.5466	6.67588	1/8	20.629	16.1007
3/32	0.00690	0.294524	3/16	3.7583	6.87223	3/16	21.135	16.2970
1/8	0.01227	0.392699	1/4	3.9761	7.06858	1/4	21.648	16.4934
5/32	0.01917	0.490874	5/16	4.2000	7.26493	5/16	22.166	16.6897
3/16	0.02761	0.589049	3/8	4.4301	7.46128	3/8	22.691	16.8861
7/32	0.03758	0.687223	7/16	4.6664	7.65763	7/16	23.221	17.0824
1/4	0.04909	0.785398	1/2	4.9087	7.85398	1/2	23.758	17.2788
9/32	0.06213	0.883573	9/16	5.1572	8.05033	9/16	24.301	17.4751
5/16	0.07670	0.981748	5/8	5.4119	8.24668	5/8	24.850	17.6715
11/32	0.09281	1.07992	11/16	5.6727	8.44303	11/16	25.406	17.8678
3/8	0.11045	1.17810	3/4	5.9396	8.63938	3/4	25.967	18.0642
13/32	0.12962	1.27627	13/16	6.2126	8.83573	13/16	26.535	18.2605
7/16	0.15033	1.37445	7/8	6.4918	9.03208	7/8	27.109	18.4569
15/32	0.17257	1.47262	15/16	6.7771	9.22843	15/16	27.688	18.6532
1/2	0.19635	1.57080	3	7.0686	9.42478	6	28.274	18.8496
17/32	0.22166	1.66897	1/16	7.3662	9.62113	1/8	29.465	19.2423
9/16	0.24850	1.76715	1/8	7.6699	9.81748	1/4	30.680	19.6350
19/32	0.27688	1.86532	3/16	7.9798	10.0138	3/8	31.919	20.0277
5/8	0.30680	1.96350	1/4	8.2958	10.2102	1/2	33.183	20.4204
21/32	0.33824	2.06167	5/16	8.6179	10.4065	5/8	34.472	20.8131
11/16	0.37122	2.15984	3/8	8.9462	10.6029	3/4	35.785	21.2058
23/32	0.40574	2.25802	7/16	9.2806	10.7992	7/8	37.122	21.5984
3/4	0.44179	2.35619	1/2	9.6211	10.9956	7	38.485	21.9911
25/32	0.47937	2.45437	9/16	9.9678	11.1919	1/8	39.871	22.3838
13/16	0.51849	2.55254	5/8	10.321	11.3883	1/4	41.282	22.7765
27/32	0.55914	2.65072	11/16	10.680	11.5846	3/8	42.718	23.1692
7/8	0.60132	2.74889	3/4	11.045	11.7810	1/2	44.179	23.5619
29/32	0.64504	2.84707	13/16	11.416	11.9773	5/8	45.664	23.9546
15/16	0.69029	2.94524	7/8	11.793	12.1737	3/4	47.173	24.3473
31/32	0.73708	3.04342	15/16	12.177	12.3700	7/8	48.707	24.7400
1	0.78540	3.14159	4	12.566	12.5664	8	50.265	25.1327
1/16	0.88664	3.33794	1/16	12.962	12.7627	1/8	51.849	25.5255
1/8	0.99402	3.53429	1/8	13.364	12.9591	1/4	53.456	25.9181
3/16	1.1075	3.73064	3/16	13.772	13.1554	3/8	55.088	26.3108
1/4	1.2272	3.92699	1/4	14.186	13.3518	1/2	56.745	26.7035
5/16	1.3530	4.12334	5/16	14.607	13.5481	5/8	58.426	27.0962
3/8	1.4849	4.31069	3/8	15.033	13.7445	3/4	60.132	27.4889
7/16	1.6230	4.51604	7/16	15.466	13.9408	7/8	61.862	27.8816
1/2	1.7671	4.71239	1/2	15.904	14.1372	9	63.617	28.2743
9/16	1.9175	4.90874	9/16	16.349	14.3335	1/8	65.397	28.6670
5/8	2.0739	5.10509	5/8	16.800	14.5299	1/4	67.201	29.0597
11/16	2.2365	5.30144	11/16	17.257	14.7262	3/8	69.029	29.4524
3/4	2.4053	5.49779	3/4	17.721	14.9226	1/2	70.882	29.8451
13/16	2.5802	5.69414	13/16	18.190	15.1189	5/8	72.760	30.2378
7/8	2.7612	5.89049	7/8	18.665	15.3153	3/4	74.662	30.6305
15/16	2.9483	6.08684	15/16	19.147	15.5116	7/8	76.589	31.0232

AREAS AND CIRCUMFERENCES OF CIRCLES FROM 1 TO 100

Dia.	Area	Circum.	Dia.	Area	Circum.	Dia.	Area	Circum.
10	78.540	31.4159	16	201.06	50.2655	22	380.13	69.1150
⅛	80.516	31.8086	⅛	204.22	50.6582	⅛	384.46	69.5077
¼	82.516	32.2013	¼	207.39	51.0509	¼	388.82	69.9004
⅜	84.541	32.5940	⅜	210.60	51.4436	⅜	393.20	70.2931
½	86.590	32.9867	½	213.82	51.8363	½	397.61	70.6858
⅝	88.664	33.3794	⅝	217.08	52.2290	⅝	402.04	71.0785
¾	90.763	33.7721	¾	220.35	52.6217	¾	406.49	71.4712
⅞	92.886	34.1648	⅞	223.65	53.0144	⅞	410.97	71.8639
11	95.033	34.5575	17	226.98	53.4071	23	415.48	72.2566
⅛	97.205	34.9502	⅛	230.33	53.7998	⅛	420.00	72.6493
¼	99.402	35.3429	¼	233.71	54.1925	¼	424.56	73.0420
⅜	101.62	35.7356	⅜	237.10	54.5852	⅜	429.13	73.4347
½	103.87	36.1283	½	240.53	54.9779	½	433.74	73.8274
⅝	106.14	36.5210	⅝	243.98	55.3706	⅝	438.36	74.2201
¾	108.43	36.9137	¾	247.45	55.7633	¾	443.01	74.6128
⅞	110.75	37.3064	⅞	250.95	56.1560	⅞	447.69	75.0055
12	113.10	37.6991	18	254.47	56.5487	24	452.39	75.3982
⅛	115.47	38.0918	⅛	258.02	56.9414	⅛	457.11	75.7909
¼	117.86	38.4845	¼	261.59	57.3341	¼	461.86	76.1836
⅜	120.28	38.8772	⅜	265.18	57.7268	⅜	466.64	76.5765
½	122.72	39.2699	½	268.80	58.1195	½	471.44	76.9690
⅝	125.19	39.6626	⅝	272.45	58.5122	⅝	476.26	77.3617
¾	127.68	40.0553	¾	276.12	58.9049	¾	481.11	77.7544
⅞	130.19	40.4480	⅞	279.81	59.2976	⅞	485.98	78.1471
13	132.73	40.8407	19	283.53	59.6903	25	490.87	78.5398
⅛	135.30	41.2334	⅛	287.27	60.0830	⅛	495.79	78.9325
¼	137.89	41.6261	¼	291.04	60.4757	¼	500.74	79.3252
⅜	140.50	42.0188	⅜	294.83	60.8684	⅜	505.71	79.7179
½	143.14	42.4115	½	298.65	61.2611	½	510.71	80.1105
⅝	145.80	42.8042	⅝	302.49	61.6538	⅝	515.72	80.5033
¾	148.49	43.1969	¾	306.35	62.0465	¾	520.77	80.8960
⅞	151.20	43.5896	⅞	310.24	62.4392	⅞	525.84	81.2887
14	153.94	43.9823	20	314.16	62.8319	26	530.93	81.6814
⅛	156.70	44.3750	⅛	318.10	63.2246	⅛	536.05	82.0741
¼	159.48	44.7677	¼	322.06	63.6173	¼	541.19	82.4668
⅜	162.30	45.1604	⅜	326.05	64.0100	⅜	546.35	82.8595
½	165.13	45.5531	½	330.06	64.4026	½	551.55	83.2522
⅝	167.99	45.9458	⅝	334.10	64.7953	⅝	556.76	83.6449
¾	170.87	46.3385	¾	338.16	65.1880	¾	562.00	84.0376
⅞	173.78	46.7312	⅞	342.25	65.5807	⅞	567.27	84.4303
15	176.71	47.1239	21	346.36	65.9734	27	572.56	84.8230
⅛	179.67	47.5166	⅛	350.50	66.3661	⅛	577.87	85.2157
¼	182.65	47.9093	¼	354.66	66.7588	¼	583.21	85.6084
⅜	185.66	48.3020	⅜	358.84	67.1515	⅜	588.57	86.0011
½	188.69	48.6947	½	363.05	67.5442	½	593.96	86.3938
⅝	191.75	49.0874	⅝	367.28	67.9369	⅝	599.37	86.7865
¾	194.83	49.4801	¾	371.54	68.3296	¾	604.81	87.1792
⅞	197.93	49.8728	⅞	375.83	68.7223	⅞	610.27	87.5719

AREAS AND CIRCUMFERENCES OF CIRCLES FROM 1 TO 100

Dia.	Area	Circum.	Dia.	Area	Circum.	Dia.	Area	Circum.
28	615.75	87.9646	34	907.92	106.814	40	1256.6	125.664
⅛	621.26	88.3573	⅛	914.61	107.207	⅛	1264.5	126.056
¼	626.80	88.7500	¼	921.32	107.600	¼	1272.4	126.449
⅜	632.36	89.1427	⅜	928.06	107.992	⅜	1280.3	126.842
½	637.94	89.5354	½	934.82	108.385	½	1288.2	127.235
⅝	643.55	89.9281	⅝	941.61	108.788	⅝	1296.2	127.627
¾	649.18	90.3208	¾	948.42	109.170	¾	1304.2	128.020
⅞	656.84	90.7135	⅞	955.25	109.563	⅞	1312.2	128.413
29	660.52	91.1062	35	962.11	109.956	41	1320.3	128.805
⅛	666.23	91.4989	⅛	969.00	110.348	⅛	1328.3	129.198
¼	671.96	91.8916	¼	975.91	110.741	¼	1336.4	129.591
⅜	677.71	92.2843	⅜	982.84	111.134	⅜	1344.5	129.993
½	683.49	92.6770	½	989.80	111.527	½	1352.7	130.376
⅝	689.30	93.0697	⅝	996.78	111.919	⅝	1360.8	130.769
¾	695.13	93.4624	¾	1003.8	112.312	¾	1369.0	131.161
⅞	700.98	93.8551	⅞	1010.8	112.705	⅞	1377.2	131.554
30	706.86	94.2478	36	1017.9	113.097	42	1385.4	131.947
⅛	712.76	94.6405	⅛	1025.0	113.490	⅛	1393.7	132.340
¼	718.69	95.0332	¼	1032.1	113.883	¼	1402.0	132.732
⅜	724.64	95.4259	⅜	1039.2	114.275	⅜	1410.3	133.125
½	730.62	95.8186	½	1046.3	114.668	½	1418.6	133.518
⅝	736.62	96.2113	⅝	1053.5	115.061	⅝	1427.0	133.910
¾	742.64	96.6040	¾	1060.7	115.454	¾	1435.4	134.303
⅞	748.69	96.9967	⅞	1068.0	115.846	⅞	1443.8	134.696
31	754.77	97.3894	37	1075.2	116.239	43	1452.2	135.088
⅛	760.87	97.7821	⅛	1082.5	116.632	⅛	1460.7	135.481
¼	766.99	98.1748	¼	1089.8	117.024	¼	1469.1	135.874
⅜	773.14	98.5675	⅜	1097.1	117.417	⅜	1477.6	136.267
½	779.31	98.9602	½	1104.5	117.810	½	1486.2	136.659
⅝	785.51	99.3529	⅝	1111.8	118.202	⅝	1494.7	137.052
¾	791.73	99.7456	¾	1119.2	118.596	¾	1503.3	137.445
⅞	797.98	100.138	⅞	1126.7	118.988	⅞	1511.9	137.837
32	804.25	100.531	38	1134.1	119.381	44	1520.5	138.230
⅛	810.54	100.924	⅛	1141.6	119.773	⅛	1529.2	138.623
¼	816.86	101.316	¼	1149.1	120.166	¼	1537.9	139.015
⅜	823.21	101.709	⅜	1156.6	120.559	⅜	1546.6	139.408
½	829.58	102.102	½	1164.2	120.951	½	1555.3	139.801
⅝	835.97	102.494	⅝	1171.7	121.344	⅝	1564.0	140.194
¾	842.39	102.887	¾	1179.3	121.737	¾	1572.8	140.586
⅞	848.83	103.280	⅞	1186.9	122.129	⅞	1581.6	140.979
33	855.30	103.673	39	1194.6	122.522	45	1590.4	141.372
⅛	861.79	104.065	⅛	1202.3	122.915	⅛	1599.3	141.764
¼	868.31	104.458	¼	1210.0	123.308	¼	1608.2	142.157
⅜	874.85	104.851	⅜	1217.7	123.700	⅜	1617.0	142.550
½	881.41	105.243	½	1225.4	124.093	½	1626.0	142.942
⅝	888.00	105.636	⅝	1233.2	124.486	⅝	1634.9	143.335
¾	894.62	106.029	¾	1241.0	124.878	¾	1643.9	143.728
⅞	901.26	106.421	⅞	1248.8	125.271	⅞	1652.9	144.121

AREAS AND CIRCUMFERENCES OF CIRCLES FROM 1 TO 100

Dia.	Area	Circum.	Dia.	Area	Circum.	Dia.	Area	Circum.
46	1661.9	144.513	52	2123.7	163.363	58	2642.1	182.212
⅛	1670.9	144.906	⅛	2133.9	163.756	⅛	2653.5	182.605
¼	1680.0	145.299	¼	2144.2	164.148	¼	2664.9	182.998
⅜	1689.1	145.691	⅜	2154.5	164.541	⅜	2676.4	183.390
½	1698.2	146.084	½	2164.8	164.934	½	2687.8	183.783
⅝	1707.4	146.477	⅝	2175.1	165.326	⅝	2699.3	184.176
¾	1716.5	146.869	¾	2185.4	165.719	¾	2710.9	184.569
⅞	1725.7	147.262	⅞	2195.8	166.112	⅞	2722.4	184.961
47	1734.9	147.655	53	2206.2	166.504	59	2734.0	185.354
⅛	1744.2	148.048	⅛	2216.6	166.897	⅛	2745.6	185.747
¼	1753.5	148.440	¼	2227.0	167.290	¼	2757.2	186.139
⅜	1762.7	148.833	⅜	2237.5	167.683	⅜	2768.8	186.532
½	1772.1	149.226	½	2248.0	168.075	½	2780.5	186.925
⅝	1781.4	149.618	⅝	2258.5	168.468	⅝	2792.2	187.317
¾	1790.8	150.011	¾	2269.1	168.861	¾	2803.9	187.710
⅞	1800.1	150.404	⅞	2279.6	169.253	⅞	2815.7	188.103
48	1809.6	150.796	54	2290.2	169.646	60	2827.4	188.496
⅛	1819.0	151.189	⅛	2300.8	170.039	⅛	2839.2	188.888
¼	1828.5	151.582	¼	2311.5	170.431	¼	2851.0	189.281
⅜	1837.9	151.975	⅜	2322.1	170.824	⅜	2862.9	189.674
½	1847.5	152.367	½	2332.8	171.217	½	2874.8	190.066
⅝	1857.0	152.760	⅝	2343.5	171.609	⅝	2886.6	190.459
¾	1866.5	153.153	¾	2354.3	172.002	¾	2898.6	190.852
⅞	1876.1	153.544	⅞	2365.0	172.395	⅞	2910.5	191.244
49	1885.7	153.938	55	2375.8	172.788	61	2922.5	191.637
⅛	1895.4	154.331	⅛	2386.6	173.180	⅛	2934.5	192.030
¼	1905.0	154.723	¼	2397.5	173.573	¼	2946.5	192.423
⅜	1914.7	155.116	⅜	2408.3	173.966	⅜	2958.5	192.815
½	1924.2	155.509	½	2419.2	174.358	½	2970.6	193.208
⅝	1934.2	155.904	⅝	2430.1	174.751	⅝	2982.7	193.601
¾	1943.9	156.294	¾	2441.1	175.144	¾	2994.8	193.993
⅞	1953.7	156.687	⅞	2452.0	175.536	⅞	3006.9	194.386
50	1963.5	157.080	56	2463.0	175.929	62	3019.1	194.779
⅛	1973.3	157.472	⅛	2474.0	176.322	⅛	3031.3	195.171
¼	1983.2	157.865	¼	2485.0	176.715	¼	3043.5	195.564
⅜	1993.1	158.258	⅜	2496.1	177.107	⅜	3055.7	195.957
½	2003.0	158.650	½	2507.2	177.500	½	3068.0	196.350
⅝	2012.9	159.043	⅝	2518.3	177.893	⅝	3080.3	196.742
¾	2022.8	159.436	¾	2529.4	178.285	¾	3092.6	197.135
⅞	2032.8	159.829	⅞	2540.6	178.678	⅞	3104.9	197.528
51	2042.8	160.221	57	2551.8	179.071	63	3117.2	197.920
⅛	2052.8	160.614	⅛	2563.0	179.463	⅛	3129.6	198.313
¼	2062.9	161.007	¼	2574.2	179.856	¼	3142.0	198.706
⅜	2073.0	161.399	⅜	2585.4	180.249	⅜	3154.5	199.098
½	2083.1	161.792	½	2596.7	180.642	½	3166.9	199.491
⅝	2093.2	162.185	⅝	2608.0	181.034	⅝	3179.4	199.884
¾	2103.3	162.577	¾	2619.4	181.427	¾	3191.9	200.277
⅞	2113.5	162.970	⅞	2630.7	181.820	⅞	3204.4	200.669

AREAS AND CIRCUMFERENCES OF CIRCLES FROM 1 TO 100

Dia.	Area	Circum.	Dia.	Area	Circum.	Dia.	Area	Circum.
64	3217.0	201.062	70	3848.5	219.911	76	4536.5	238.761
⅛	3229.6	201.455	⅛	3862.2	220.304	⅛	4551.4	239.154
¼	3242.2	201.847	¼	3876.0	220.697	¼	4566.4	239.546
⅜	3254.8	202.240	⅜	3889.8	221.090	⅜	4581.3	239.939
½	3267.5	202.633	½	3903.6	221.482	½	4596.3	240 332
⅝	3280.1	203.025	⅝	3917.5	221.875	⅝	4611.4	240.725
¾	3292.8	203.418	¾	3931.4	222.268	¾	4626.4	241.117
⅞	3305.6	203.811	⅞	3945.3	222.660	⅞	4641.5	241.510
65	3318.3	204.204	71	3959.2	223.053	77	4656.6	241.903
⅛	3331.1	204.596	⅛	3973.1	223.446	⅛	4671.8	242.295
¼	3343.9	204.989	¼	3987.1	223.838	¼	4686.9	242.688
⅜	3356.7	205.382	⅜	4001.1	224.231	⅜	4702.1	243.081
½	3369.6	205.774	½	4015.2	224.624	½	4717.3	243.473
⅝	3382.4	206.167	⅝	4029.2	225.017	⅝	4732.5	243.866
¾	3395.3	206.560	¾	4043.3	225.409	¾	4747.8	244.259
⅞	3408.2	206.952	⅞	4057.4	225.802	⅞	4763.1	244.652
66	3421.2	207.345	72	4071.5	226.195	78	4778.4	245.044
⅛	3434.3	207.738	⅛	4085.7	226.587	⅛	4793.7	245.437
¼	3447.2	208.131	¼	4099.8	226.930	¼	4809.0	245.830
⅜	3460.2	208.523	⅜	4114.0	227.373	⅜	4824.4	246.222
½	3473.2	208.916	½	4128.2	227.765	½	4839.8	246.615
⅝	3486.3	209.309	⅝	4142.5	228.158	⅝	4855.2	247.008
¾	3499.4	209.701	¾	4156.8	228.551	¾	4870.7	247.400
⅞	3512.5	210.094	⅞	4171.1	228.944	⅞	4886.2	247.793
67	3525.7	210.487	73	4185.4	229.336	79	4901.7	248.186
⅛	3538.8	210.879	⅛	4199.7	229.729	⅛	4917.2	248.579
¼	3552.0	211.272	¼	4214.1	230.122	¼	4932.7	248.971
⅜	3565.2	211.665	⅜	4228.5	230.514	⅜	4948.3	249.364
½	3578.5	212.058	½	4242.9	230.907	½	4963.9	249.757
⅝	3591.7	212.450	⅝	4257.4	231.300	⅝	4979.5	250.149
¾	3605.0	212.843	¾	4271.8	231.692	¾	4995.2	250.542
⅞	3618.3	213.236	⅞	4286.3	232.085	⅞	5010.9	250.935
68	3631.7	213.628	74	4300.8	232.478	80	5026.5	251.327
⅛	3645.0	214.021	⅛	4315.4	232.871	⅛	5042.3	251.720
¼	3658.4	214.414	¼	4329.9	233.263	¼	5058.0	252.113
⅜	3671.8	214.806	⅜	4344.5	233.656	⅜	5073.8	252.506
½	3685.3	215.199	½	4359.2	234.049	½	5089.6	252.898
⅝	3698.7	215.592	⅝	4373.8	234.441	⅝	5105.4	253.291
¾	3712.2	215.984	¾	4388.5	234.834	¾	5121.2	253.684
⅞	3725.7	216.337	⅞	4403.1	235.227	⅞	5137.1	254.076
69	3739.3	216.770	75	4417.9	235.619	81	5153.0	254.469
⅛	3752.8	217.163	⅛	4432.6	236.012	⅛	5168.9	254.862
¼	3766.4	217.555	¼	4447.4	236.405	¼	5184.9	255.254
⅜	3780.0	217.948	⅜	4462.2	236.798	⅜	5200.8	255.647
½	3793.7	218.341	½	4477.0	237.190	½	5216.8	256.040
⅝	3807.3	218.733	⅝	4491.8	237.583	⅝	5232.8	256.433
¾	3821.0	219.126	¾	4506.7	237.976	¾	5248.9	256.825
⅞	3834.7	219.519	⅞	4521.5	238.368	⅞	5264.9	257.218

AREAS AND CIRCUMFERENCES OF CIRCLES FROM 1 TO 100

Dia.	Area	Circum.	Dia.	Area	Circum.	Dia.	Area	Circum.
82	5281.0	257.611	88	6082.1	276.460	94	6939.8	295.310
⅛	5297.1	258.003	⅛	6099.4	276.853	⅛	6958.2	295.702
¼	5313.3	258.396	¼	6116.7	277.846	¼	6976.7	296.095
⅜	5329.4	258.789	⅜	6134.1	277.638	⅜	6995.3	296.488
½	5345.6	259.181	½	6151.4	278.031	½	7013.8	296.881
⅝	5361.8	259.574	⅝	6168.8	278.424	⅝	7032.4	297.273
¾	5378.1	259.967	¾	6186.2	278.816	¾	7051.0	297.666
⅞	5394.3	260.359	⅞	6203.7	279.209	⅞	7069.6	298.059
83	5410.6	260.752	89	6221.1	279.602	95	7088.2	298.451
⅛	5426.9	261.145	⅛	6238.6	279.994	⅛	7106.9	298.844
¼	5443.3	261.538	¼	6256.1	280.387	¼	7125.6	299.237
⅜	5459.6	261.930	⅜	6273.7	280.780	⅜	7144.3	299.629
½	5476.0	262.323	½	6291.2	281.173	½	7163.0	300.022
⅝	5492.4	262.716	⅝	6308.8	281.565	⅝	7181.8	300.415
¾	5508.8	263.103	¾	6326.4	281.958	¾	7200.6	300.807
⅞	5525.3	263.501	⅞	6344.1	282.351	⅞	7219.4	301.200
84	5541.8	263.894	90	6361.7	282.743	96	7238.2	301.593
⅛	5558.3	264.286	⅛	6379.4	283.136	⅛	7257.1	301.986
¼	5574.8	264.679	¼	6397.1	283.529	¼	7276.0	302.378
⅜	5591.4	265.072	⅜	6414.9	283.921	⅜	7294.9	302.771
½	5607.9	265.465	½	6432.6	284.314	½	7313.8	303.164
⅝	5624.5	265.857	⅝	6450.4	284.707	⅝	7332.8	303.556
¾	5641.2	266.250	¾	6468.2	285.100	¾	7351.8	303.949
⅞	5657.8	266.643	⅞	6486.0	285.492	⅞	7370.8	304.342
85	5674.5	267.035	91	6503.9	285.885	97	7389.8	304.734
⅛	5691.2	267.428	⅛	6521.8	286.278	⅛	7408.9	305.127
¼	5707.9	267.821	¼	6539.7	286.670	¼	7428.0	305.520
⅜	5724.7	268.213	⅜	6557.6	287.063	⅜	7447.1	305.913
½	5741.5	268.606	½	6575.5	287.456	½	7466.2	306.305
⅝	5758.3	268.999	⅝	6593.5	287.848	⅝	7485.3	306.698
¾	5775.1	269.392	¾	6611.5	288.241	¾	7504.5	307.091
⅞	5791.9	269.784	⅞	6629.6	288.634	⅞	7523.7	307.483
86	5808.8	270.177	92	6647.6	289.027	98	7543.0	307.876
⅛	5825.7	270.570	⅛	6665.7	289.419	⅛	7562.2	308.269
¼	5842.6	270.962	¼	6683.8	289.812	¼	7581.5	308.661
⅜	5859.6	271.355	⅜	6701.9	290.205	⅜	7600.8	309.064
½	5876.5	271.748	½	0720.1	290.597	½	7620.1	309.447
⅝	5893.5	272.140	⅝	6738.2	290.990	⅝	7639.5	309.840
¾	5910.6	272.533	¾	6756.4	291.383	¾	7658.9	310.232
⅞	5927.6	272.926	⅞	6774.7	291.775	⅞	7678.3	310.625
87	5944.7	273.319	93	6792.9	292.168	99	7697.7	311.018
⅛	5961.8	273.711	⅛	6811.2	292.561	⅛	7717.1	311.410
¼	5978.9	274.104	¼	6829.5	292.954	¼	7736.6	311.803
⅜	5996.0	274.497	⅜	6847.8	293.346	⅜	7756.1	312.196
½	6013.2	274.889	½	6866.1	293.739	½	7775.6	312.588
⅝	6030.4	275.282	⅝	6884.5	294.132	⅝	7795.2	312.981
¾	6047.6	275.675	¾	6902.9	294.524	¾	7814.8	313.374
⅞	6064.9	276.067	⅞	6921.3	294.917	⅞	7834.4	313.767

Areas and Circumferences of Circles from 100 to 1000

Diam.	Area.	Circum.	Diam.	Area	Circum.	Diam.	Area	Circum.
100	7853.98	314.16	150	17671.46	471.24	200	31415.93	628.32
101	8011.85	317.30	151	17907.86	474.38	201	31730.87	631.46
102	8171.28	320.44	152	18145.84	477.52	202	32047.39	634.60
103	8332.29	323.58	153	18385.39	480.66	203	32365.47	637.74
104	8494.87	326.73	154	18626.50	483.81	204	32685.13	640.88
105	8659.01	329.87	155	18869.19	486.95	205	33006.36	644.03
106	8824.73	333.01	156	19113.45	490.09	206	33329.16	647.17
107	8992.02	336.15	157	19359.28	493.23	207	33653.53	650.31
108	9160.88	339.29	158	19606.68	496.37	208	33979.47	653.45
109	9331.32	342.43	159	19855.65	499.51	209	34306.98	656.59
110	9503.32	345.58	160	20106.19	502.65	210	34636.06	659.73
111	9676.89	348.72	161	20358.31	505.80	211	34966.71	662.88
112	9852.03	351.86	162	20611.99	508.94	212	35298.94	666.02
113	10028.75	355.00	163	20867.24	512.08	213	35632.73	669.16
114	10207.03	358.14	164	21124.07	515.22	214	35968.09	672.30
115	10386.89	361.28	165	21382.46	518.36	215	36305.03	675.44
116	10568.32	364.42	166	21642.43	521.50	216	36643.54	678.58
117	10751.32	367.57	167	21903.97	524.65	217	36983.61	681.73
118	10935.88	370.71	168	22167.08	527.79	218	37325.26	684.87
119	11122.02	373.85	169	22431.76	530.93	219	37668.48	688.01
120	11309.73	376.99	170	22698.01	534.07	220	38013.27	691.15
121	11499.01	380.13	171	22965.83	537.21	221	38359.63	694.29
122	11689.87	383.27	172	23235.22	540.35	222	38707.56	697.43
123	11882.29	386.42	173	23506.18	543.50	223	39057.07	700.58
124	12076.28	389.56	174	23778.71	546.64	224	39408.14	703.72
125	12271.85	392.70	175	24052.82	549.78	225	39760.78	706.86
126	12468.98	395.84	176	24328.49	552.92	226	40115.00	710.00
127	12667.69	398.98	177	24605.74	556.06	227	40470.78	713.14
128	12867.96	402.12	178	24884.56	559.20	228	40828.14	716.28
129	13069.81	405.27	179	25164.94	562.35	229	41187.07	719.42
130	13273.23	408.41	180	25446.90	565.49	230	41547.56	722.57
131	13478.22	411.55	181	25730.43	568.63	231	41909.63	725.71
132	13684.78	414.69	182	26015.53	571.77	232	42273.27	728.85
133	13892.91	417.83	183	26302.20	574.91	233	42638.48	731.99
134	14102.61	420.97	184	26590.44	578.05	234	43005.26	735.13
135	14313.88	424.12	185	26880.25	581.19	235	43373.61	738.27
136	14526.72	427.26	186	27171.63	584.34	236	43743.54	741.42
137	14741.14	430.40	187	27464.59	587.48	237	44115.03	744.56
138	14957.12	433.54	188	27759.11	590.62	238	44488.09	747.70
139	15174.68	436.68	189	28055.21	593.76	239	44862.73	750.84
140	15393.80	439.82	190	28352.87	596.90	240	45238.93	753.98
141	15614.50	442.96	191	28652.11	600.04	241	45616.71	757.12
142	15836.77	446.11	192	28952.92	603.19	242	45996.06	760.27
143	16060.61	449.25	193	29255.30	606.33	243	46376.98	763.41
144	16286.02	452.39	194	29559.25	609.47	244	46759.47	766.55
145	16513.00	455.53	195	29864.77	612.61	245	47143.52	769.69
146	16741.55	458.67	196	30171.86	615.75	246	47529.16	772.83
147	16971.67	461.81	197	30480.52	618.89	247	47916.36	775.97
148	17203.36	464.96	198	30790.75	622.04	248	48305.13	779.11
149	17436.62	468.10	199	31102.55	625.18	249	48695.47	782.26

These tables have been limited to 1,000 in the belief that this covers all the usual requirements.

Should it be necessary to find the area or circumference of circles of larger diameter, it is only necessary to remember that areas increase with the *square* of the diameter and that the circumference increases *directly* with the diameter. In other words, *doubling* the diameter also *doubles* the circumference but increases the area *four times.*

AREAS AND CIRCUMFERENCES OF CIRCLES FROM 100 TO 1000

Diam.	Area	Circum.	Diam.	Area	Circum.	Diam.	Area	Circum.
250	49087.39	785.40	300	70685.83	942.48	350	96211.28	1099.56
251	49480.87	788.54	301	71157.86	945.62	351	96761.84	1102.70
252	49875.92	791.68	302	71631.45	948.76	352	97313.97	1105.84
253	50272.55	794.82	303	72106.62	951.90	353	97867.68	1108.98
254	50670.75	797.96	304	72583.36	955.04	354	98422.96	1112.12
255	51070.52	801.11	305	73061.66	958.19	355	98979.80	1115.27
256	51471.85	804.25	306	73541.54	961.33	356	99538.22	1118.41
257	51874.76	807.39	307	74022.99	964.47	357	100098.21	1121.55
258	52279.24	810.53	308	74506.01	967.61	358	100659.77	1124.69
259	52685.29	813.67	309	74990.60	970.75	359	101222.90	1127.83
260	53092.92	816,81	310	75476.76	973.89	360	101787.60	1130.97
261	53502.11	819.96	311	75964.50	977.04	361	102353.87	1134.11
262	53912.87	823.10	312	76453.80	980.18	362	102921.72	1137.26
263	54325.21	826.24	313	76944.67	983.32	363	103491.13	1140.40
264	54739.11	829.38	314	77437.12	986.46	364	104062.12	1143.54
265	55154.59	832.52	315	77931.13	989.60	365	104634.67	1146.68
266	55571.63	835.66	316	78426.72	992.74	366	105208.80	1149.82
267	55990.25	838.81	317	78923.88	995.88	367	105784.49	1152.96
268	56410.44	841.95	318	79422.60	999.03	368	106361.76	1156.11
269	56832.20	845.09	319	79922.90	1002.17	369	106940.60	1159.25
270	57255.53	848.23	320	80424.77	1005.31	370	107521.01	1162.39
271	57680.43	851.37	321	80928.21	1008.45	371	108102.99	1165.53
272	58106.90	854.51	322	81433.22	1011.59	372	108686.54	1168.67
273	58534.94	857.65	323	81939.80	1014.73	373	109271.66	1171.81
274	58964.55	860.80	324	82447.96	1017.88	374	109858.35	1174.96
275	59395.74	863.94	325	82957.68	1021.02	375	110446.62	1178.10
276	59828.49	867.08	326	83468.98	1024.16	376	111036.45	1181.24
277	60262.82	870.22	327	83981.84	1027.30	377	111627.86	1184.38
278	60698.71	873.36	328	84496.28	1030.44	378	112220.83	1187.52
279	61136.18	876.50	329	85012.28	1033.58	379	112815.38	1190.66
280	61575.22	879.65	330	85529.86	1036.73	380	113411.49	1193.81
281	62015.82	882.79	331	86049.01	1039.87	381	114009.18	1196.95
282	62458.00	885.93	332	86569.73	1043.01	382	114608.44	1200.09
283	62901.75	889.07	333	87092.02	1046.15	383	115209.27	1203.23
284	63347.07	892.21	334	87615.88	1049.29	384	115811.67	1206.37
285	63793.97	895.35	335	88141.31	1052.43	385	116415.64	1209.51
286	64242.43	898.50	336	88668.31	1055.58	386	117021.18	1212.65
287	64692.46	901.64	337	89196.88	1058.72	387	117628.30	1215.80
288	65144.07	904.78	338	89727.03	1061.86	388	118236.98	1218.94
289	65597.24	907.92	339	90258.74	1065.00	389	118847.24	1222.08
290	66051.99	911.06	340	90792.03	1068.14	390	119459.06	1225.22
291	66508.30	914.20	341	91326.88	1071.28	391	120072.46	1228.36
292	66966.19	917.35	342	91863.31	1074.42	392	120687.42	1231.50
293	67425.65	920.49	343	92401.31	1077.57	393	121303.96	1234.65
294	67886.68	923.63	344	92940.88	1080.71	394	121922.07	1237.79
295	68349.28	926.77	345	93482.02	1083.85	395	122541.75	1240.93
296	68813.45	929.91	346	94024.73	1086.99	396	123163.00	1244.07
297	69279.19	933.05	347	94569.01	1090.13	397	123785.82	1247.21
298	69746.50	936.19	348	95114.86	1093.27	398	124410.21	1250.35
299	70215.38	939.34	349	95662.28	1096.42	399	125036.17	1253.50

is 1,124. Half of 1124 is 562. The table shows the area of 562 to be 248,063.30. Multiplying this by 4 gives 892,253.20. The circumference of 562 is 1,765.58. Multiplying this by 2 gives 3,531.16.

To find the area of 5,000, take the area of 1,000 from the table and multiply it by 25, because 25 is the *square* of 5. For the circumference multiply the circumference given in the table by 5.

AREAS AND CIRCUMFERENCES OF CIRCLES FROM 100 TO 1000

Diam.	Area	Circum.	Diam.	Area	Circum.	Diam.	Area	Circum.
400	125663.71	1256.64	450	159043.13	1413.72	500	196349.54	1570.80
401	126292.81	1259.78	451	159750.77	1416.86	501	197135.72	1573.94
402	126923.48	1262.92	452	160459.99	1420.00	502	197923.48	1577.08
403	127555.73	1266.06	453	161170.77	1423.14	503	198712.80	1580.22
404	128189.55	1269.20	454	161883.13	1426.28	504	199503.70	1583.36
405	128824.93	1272.35	455	162597.05	1429.42	505	200296.17	1586.50
406	129461.89	1275.49	456	163312.55	1432.57	506	201090.20	1589.65
407	130100.42	1278.63	457	164029.62	1435.71	507	201885.81	1592.79
408	130740.52	1281.77	458	164748.26	1438.85	508	202682.99	1595.93
409	131382.19	1284.91	459	165468.47	1441.99	509	203481.74	1599.07
410	132025.43	1288.05	460	166190.25	1445.13	510	204282.06	1602.21
411	132670.24	1291.19	461	166913.60	1448.27	511	205083.95	1605.35
412	133316.63	1294.34	462	167638.53	1451.42	512	205887.42	1608.50
413	133964.58	1297.48	463	168365.02	1454.56	513	206692.45	1611.64
414	134614.10	1300.62	464	169093.08	1457.70	514	207499.05	1614.78
415	135265.20	1303.76	465	169822.72	1460.84	515	208307.23	1617.92
416	135917.86	1306.90	466	170553.92	1463.98	516	209116.97	1621.06
417	136572.10	1310.04	467	171286.70	1467.12	517	209928.29	1624.20
418	137227.91	1313.19	468	172021.05	1470.27	518	210741.18	1627.34
419	137885.29	1316.33	469	172756.97	1473.41	519	211555.63	1630.49
420	138544.24	1319.47	470	173494.45	1476.55	520	212371.66	1633.63
421	139204.76	1322.61	471	174233.51	1479.69	521	213189.26	1636.77
422	139866.85	1325.75	472	174974.14	1482.83	522	214008.43	1639.91
423	140530.51	1328.89	473	175716.35	1485.97	523	214829.17	1643.05
424	141195.74	1332.04	474	176460.12	1489.11	524	215651.49	1646.19
425	141862.54	1335.18	475	177205.46	1492.26	525	216475.37	1649.34
426	142530.92	1338.32	476	177952.37	1495.40	526	217300.82	1652.48
427	143200.86	1341.46	477	178700.86	1498.54	527	218127.85	1655.62
428	143872.38	1344.60	478	179450.91	1501.68	528	218956.44	1658.76
429	144545.46	1347.74	479	180202.54	1504.82	529	219786.61	1661.90
430	145220.12	1350.88	480	180955.74	1507.96	530	220618.34	1665.04
431	145896.35	1354.03	481	181710.50	1511.11	531	221451.65	1668.19
432	146574.15	1357.17	482	182466.84	1514.25	532	222286.53	1671.33
433	147253.52	1360.31	483	183224.75	1517.39	533	223122.98	1674.47
434	147934.46	1363.45	484	183984.23	1520.53	534	223961.00	1677.61
435	148616.97	1366.59	485	184745.28	1523.67	535	224800.59	1680.75
436	149301.05	1369.73	486	185507.90	1526.81	536	225641.75	1683.89
437	149986.70	1372.88	487	186272.10	1529.96	537	226484.48	1687.04
438	150673.93	1376.02	488	187037.86	1533.10	538	227328.79	1690.18
439	151362.72	1379.16	489	187805.19	1536.24	539	228174.66	1693.32
440	152053.08	1382.30	490	188574.10	1539.38	540	229022.10	1696.46
441	152745.02	1385.44	491	189344.57	1542.52	541	229871.12	1699.60
442	153438.53	1388.58	492	190116.62	1545.66	542	230721.71	1702.74
443	154133.60	1391.73	493	190890.24	1548.81	543	231573.86	1705.88
444	154830.25	1394.87	494	191665.43	1551.95	544	232427.59	1709.03
445	155528.47	1398.01	495	192442.18	1555.09	545	233282.89	1712.17
446	156228.26	1401.15	496	193220.51	1558.23	546	234139.76	1715.31
447	156929.62	1404.29	497	194000.41	1561.37	547	234998.20	1718.45
448	157632.55	1407.43	498	194781.89	1564.51	548	235858.21	1721.59
449	158337.06	1410.58	499	195564.93	1567.65	549	236719.79	1724.73

AREAS AND CIRCUMFERENCES OF CIRCLES FROM 100 TO 1000

Diam.	Area	Circum.	Diam.	Area	Circum.	Diam.	Area	Circum.
550	237582.94	1727.88	600	282743.34	1884.96	650	331830.72	2042.04
551	238447.67	1731.02	601	283686.60	1888.10	651	332852.53	2045.18
552	239313.96	1734.16	602	284631.44	1891.24	652	333875.90	2048.32
553	240181.83	1737.30	603	285577.84	1894.38	653	334900.85	2051.46
554	241051.26	1740.44	604	286525.82	1897.52	654	335927.36	2054.60
555	241922.27	1743.58	605	287475.36	1900.66	655	336955.45	2057.74
556	242794.85	1746.73	606	288426.48	1903.81	656	337985.10	2060.88
557	243668.99	1749.87	607	289379.17	1906.95	657	339016.33	2064.03
558	244544.71	1753.01	608	290333.43	1910.09	658	340049.13	2067.17
559	245422.00	1756.15	609	291289.26	1913.23	659	341083.50	2070.31
560	246300.86	1759.29	610	292246.66	1916.37	660	342119.44	2073.45
561	247181.30	1762.43	611	293205.63	1919.51	661	343156.95	2076.59
562	248063.30	1765.58	612	294166.17	1922.65	662	344196.03	2079.73
563	248946.87	1768.72	613	295128.28	1925.80	663	345236.69	2082.88
564	249832.01	1771.86	614	296091.97	1928.94	664	346278.91	2086.02
565	250718.73	1775.00	615	297057.22	1932.08	665	347322.70	2089.16
566	251607.01	1778.14	616	298024.05	1935.22	666	348368.07	2092.30
567	252496.87	1781.28	617	298992.44	1938.36	667	349415.00	2095.44
568	253388.30	1784.42	618	299962.41	1941.50	668	350463.51	2098.58
569	254281.29	1787.57	619	300933.95	1944.65	669	351513.59	2101.73
570	255175.86	1790.71	620	301907.05	1947.79	670	352565.24	2104.87
571	256072.00	1793.85	621	302881.73	1950.93	671	353618.45	2108.01
572	256969.71	1796.99	622	303857.98	1954.07	672	354673.24	2111.15
573	257868.99	1800.13	623	304835.80	1957.21	673	355729.60	2114.29
574	258769.85	1803.27	624	305815.20	1960.35	674	356787.54	2117.43
575	259672.27	1806.42	625	306796.16	1963.50	675	357847.04	2120.58
576	260576.26	1809.56	626	307778.69	1966.64	676	358908.11	2123.72
577	261481.83	1812.70	627	308762.79	1969.78	677	359970.75	2126.86
578	262388.96	1815.84	628	309748.47	1972.92	678	361034.97	2130.00
579	263297.67	1818.98	629	310735.71	1976.06	679	362100.75	2133.14
580	264207.94	1822.12	630	311724.53	1979.20	680	363168.11	2136.28
581	265119.79	1825.27	631	312714.92	1982.35	681	364237.04	2139.42
582	266033.21	1828.41	632	313706.88	1985.49	682	365307.54	2142.57
583	266948.20	1831.55	633	314700.40	1988.63	683	366379.60	2145.71
584	267864.76	1834.69	634	315695.50	1991.77	684	367453.24	2148.85
585	268782.89	1837.83	635	316692.17	1994.91	685	368528.45	2151.99
586	269702.59	1840.97	636	317690.42	1998.05	686	369605.23	2155.13
587	270623.86	1844.11	637	318690.23	2001.19	687	370683.59	2158.27
588	271546.70	1847.26	638	319691.61	2004.34	688	371763.51	2161.42
589	272471.12	1850.40	639	320694.56	2007.48	689	372845.00	2164.56
590	273397.10	1853.54	640	321699.09	2010.62	690	373028.07	2167.70
591	274324.66	1856.68	641	322705.18	2013.76	691	375012.70	2170.84
592	275253.78	1859.82	642	323712.85	2016.90	692	376098.91	2173.98
593	276184.48	1862.96	643	324722.09	2020.04	693	377186.68	2177.12
594	277116.75	1866.11	644	325732.89	2023.19	694	378276.03	2180.27
595	278050.58	1869.25	645	326745.27	2026.33	695	379366.93	2183.41
596	278985.99	1872.39	646	327759.22	2029.47	696	380459.44	2186.55
597	279922.97	1875.53	647	328774.74	2032.61	697	381553.50	2189.69
598	280861.52	1878.67	648	329791.83	2035.75	698	382649.13	2192.83
599	281801.65	1881.81	649	330810.49	2038.89	699	383746.33	2195.97

AREAS AND CIRCUMFERENCES OF CIRCLES FROM 100 TO 1000

Diam.	Area	Circum.	Diam.	Area	Circum.	Diam.	Area	Circum.
700	384845.10	2199.11	750	441786.47	2356.19	800	502654.82	2513.27
701	385945.44	2202.26	751	442965.35	2359.34	801	503912.25	2516.42
702	387047.36	2205.40	752	444145.80	2362.48	802	505171.24	2519.56
703	388150.84	2208.54	753	445327.83	2365.62	803	506431.80	2522.70
704	389255.90	2211.68	754	446511.42	2368.76	804	507693.94	2525.84
705	390362.52	2214.82	755	447696.59	2371.90	805	508957.64	2528.98
706	391470.72	2217.96	756	448883.32	2375 04	806	510222.92	2532.12
707	392580.49	2221.11	757	450071.63	2378.19	807	511489.77	2535.27
708	393691.82	2224.25	758	451261.51	2381.33	808	512758.19	2538.41
709	394804.73	2227.39	759	452452.96	2384.47	809	514028.18	2541.55
710	395919.21	2230.53	760	453645.98	2387.61	810	515299.74	2544.69
711	397035.26	2233.67	761	454840.57	2390.75	811	516572.87	2547.83
712	398152.89	2236.81	762	456036.73	2393.89	812	517847.57	2550.97
713	399272.08	2239.96	763	457234.46	2397.04	813	519123.84	2554.11
714	400392.84	2243.10	764	458433.77	2400.18	814	520401.68	2557.26
715	401515.18	2246.24	765	459634.64	2403.32	815	521681.10	2560.40
716	402639.08	2249.38	766	460837.08	2406.46	816	522962.08	2563.54
717	403764.56	2252.52	767	462041.10	2409.60	817	524244.63	2566.68
718	404891.60	2255.66	768	463246.69	2412.74	818	525528.76	2569.82
719	406020.22	2258.81	769	464453.84	2415.88	819	526814.46	2572.96
720	407150.41	2261.95	770	465662.57	2419.03	820	528101.73	2576.11
721	408282.17	2265.09	771	466872.87	2422.17	821	529390.56	2579.25
722	409415.50	2268.23	772	468084.74	2425.31	822	530680.97	2582.39
723	410550.40	2271.37	773	469298.18	2428.45	823	531972.95	2585.53
724	411686.87	2274.51	774	470513.19	2431.59	824	533266.50	2588.67
725	412824.91	2277.65	775	471729.77	2434.73	825	534561.62	2591.81
726	413964.52	2280.80	776	472947.92	2437.88	826	535858.32	2594 96
727	415105.71	2283.94	777	474167.65	2441.02	827	537156.58	2598.10
728	416248.46	2287.08	778	475388.94	2444.16	828	538456.41	2601.24
729	417392.79	2290.22	779	476611.81	2447.30	829	539757.82	2604.38
730	418538.68	2293.36	780	477836.24	2450.44	830	541060.79	2607.52
731	419686.15	2296.50	781	479062.25	2453.58	831	542365.34	2610.66
732	420835.19	2299.65	782	480289.83	2456.73	832	543671.46	2613.81
733	421985.79	2302.79	783	481518.97	2459.87	833	544979.15	2616.95
734	423137.97	2305.93	784	482749.69	2463.01	834	546288.40	2620.09
735	424291.72	2309.07	785	483981.98	2466.15	835	547599.23	2623.23
736	425447.04	2312.21	786	485215.84	2469.29	836	548911.63	2626.37
737	426603.94	2315.35	787	486451.28	2472.43	837	550225.61	2629.51
738	427762.40	2318.50	788	487688.28	2475.58	838	551541.15	2632.65
739	428922.43	2321.64	789	488926.85	2478.72	839	552858.26	2635.80
740	430084.03	2324.78	790	490166.99	2481.86	840	554176.94	2638.94
741	431247.21	2327.92	791	491408.71	2485.00	841	555497.20	2642.08
742	432411.95	2331.06	792	492651.99	2488.14	842	556819.02	2645.22
743	433578.27	2334.20	793	493896.85	2491.28	843	558142.42	2648.36
744	434746.16	2337.34	794	495143.28	2494.42	844	559467.39	2651.50
745	435915.62	2340.49	795	496391.27	2497.57	845	560793.92	2654.65
746	437086.64	2343.63	796	497640.84	2500.71	846	562122.03	2657.79
747	438259.24	2346.77	797	498891.98	2503.85	847	563451.71	2660.93
748	439433.41	2349.91	798	500144.69	2506.99	848	564782.96	2664.07
749	440609.16	2353.05	799	501398.97	2510.13	849	566115.78	2667.21

AREAS AND CIRCUMFERENCES OF CIRCLES FROM 100 TO 1000

Diam.	Area	Circum.	Diam.	Area	Circum.	Diam.	Area	Circum.
850	567450.17	2670.35	900	636172.51	2827.43	950	708821.84	2984.51
851	568786.14	2673.50	901	637587.01	2830.58	951	710314.88	2987.65
852	570123.67	2676.64	902	639003.09	2833.72	952	711809.50	2990.80
853	571462.77	2679.78	903	640420.73	2836.86	953	713305.68	2993.94
854	572803.45	2682.92	904	641839.95	2840.00	954	714803.43	2997.08
855	574145.69	2686.06	905	643260.73	2843.14	955	716302.76	3000.22
856	575489.51	2689.20	906	644683.09	2846.28	956	717803.66	3003.36
857	576834.90	2692.34	907	646107.01	2849.42	957	719306.12	3006.50
858	578181.85	2695.49	908	647532.51	2852.57	958	720810.16	3009.65
859	579530.38	2698.63	909	648959.58	2855.71	959	722315.77	3012.79
860	580880.48	2701.77	910	650388.22	2858.85	960	723822.95	3015.93
861	582232.15	2704.91	911	651818.43	2861.99	961	725331.70	3019.07
862	583585.39	2708.05	912	653250.21	2865.13	962	726842.02	3022.21
863	584940.20	2711.19	913	654683.56	2868.27	963	728353.91	3025.35
864	586296.59	2714.34	914	656118.48	2871.42	964	729867.37	3028.50
865	587654.54	2717.48	915	657554.98	2874.56	965	731382.40	3031.64
866	589014.07	2720.62	916	658993.04	2877.70	966	732899.01	3034.78
867	590375.16	2723.76	917	660432.68	2880.84	967	734417.18	3037.92
868	591737.83	2726.90	918	661873.88	2883.98	968	735936.93	3041.06
869	593102.06	2730.04	919	663316.66	2887.12	969	737458.24	3044.20
870	594467.87	2733.19	920	664761.01	2890.27	970	738981.13	3047.34
871	595835.25	2736.33	921	666206.92	2893.41	971	740505.59	3050.49
872	597204.20	2739.47	922	667654.41	2896.55	972	742031.62	3053.63
873	598574.72	2742.61	923	669103.47	2899.69	973	743559.22	3056.77
874	599946.81	2745.75	924	670554.10	2902.83	974	745088.39	3059.91
875	601320.47	2748.89	925	672006.30	2905.97	975	746619.13	3063.05
876	602695.70	2752.04	926	673460.08	2909.11	976	748151.44	3066.19
877	604072.50	2755.18	927	674915.42	2912.26	977	749685.32	3069.34
878	605450.88	2758.32	928	676372.33	2915.40	978	751220.78	3072.48
879	606830.82	2761.46	929	677830.82	2918.54	979	752757.80	3075.62
880	608212.34	2764.60	930	679290.87	2921.68	980	754296.40	3078.76
881	609595.42	2767.74	931	680752.50	2924.82	981	755836.59	3081.90
882	610980.08	2770.88	932	682215.69	2927.96	982	757378.30	3085.04
883	612366.31	2774.03	933	683680.46	2931.11	983	758921.61	3088.19
884	613754.11	2777.17	934	685146.80	2934.25	984	760466.48	3091.33
885	615143.48	2780.31	935	686614.71	2937.39	985	762012.93	3094.47
886	616534.42	2783.45	936	688084.19	2940.53	986	763560.95	3097.61
887	617926.93	2786.59	937	689555.24	2943.67	987	765110.54	3100.75
888	619321.01	2789.73	938	691027.86	2946.81	988	766661.70	3103.89
889	620716.66	2792.88	939	692502.05	2949.96	989	768214.44	3107.04
890	622113.89	2796.02	940	693977.82	2953.10	990	769768.74	3110.18
891	623512.68	2799.16	941	695455.15	2956.24	991	771324.61	3113.32
892	624913.04	2802.30	942	696934.06	2959.38	992	772882.06	3116.46
893	626314.98	2805.44	943	698414.53	2962.52	993	774441.07	3119.60
894	627718.49	2808.58	944	699896.58	2965.66	994	776001.66	3122.74
895	629123.56	2811.73	945	701380.19	2968.81	995	777563.82	3125.88
896	630530.21	2814.87	946	702865.38	2971.95	996	779127.54	3129.03
897	631938.43	2818.01	947	704352.14	2975.09	997	780692.84	3132.17
898	633348.22	2821.15	948	705840.47	2978.23	998	782259.71	3135.31
899	634759.58	2824.29	949	707330.37	2981.37	999	783828.15	3138.45
						1000	785398.16	3141.59

Circumferences and Diameters of Circles

Circum.	Diameter	Circum.	Diameter	Circum.	Diameter	Circum.	Diameter
1	.3183	51	16.2338	101	32.1493	151	48.0648
2	.6366	52	16.5521	102	32.4676	152	48.3831
3	.9549	53	16.8704	103	32.7859	153	48.7014
4	1.2732	54	17.1887	104	33.1042	154	49.0197
5	1.5915	55	17.5070	105	33.4225	155	49.3380
6	1.9099	56	17.8254	106	33.7408	156	49.6563
7	2.2282	57	18.1437	107	34.0592	157	49.9747
8	2.5465	58	18.4620	108	34.3775	158	50.2930
9	2.8648	59	18.7803	109	34.6958	159	50.6113
10	3.1831	60	19.0986	110	35.0141	160	50.9296
11	3.5014	61	19.4169	111	35.3324	161	51.2479
12	3.8197	62	19.7352	112	35.6507	162	51.5662
13	4.1380	63	20.0535	113	35.9690	163	51.8845
14	4.4563	64	20.3718	114	36.2873	164	52.2028
15	4.7746	65	20.6901	115	36.6056	165	52.5211
16	5.0930	66	21.0085	116	36.9239	166	52.8394
17	5.4113	67	21.3268	117	37.2423	167	53.1578
18	5.7296	68	21.6451	118	37.5606	168	53.4761
19	6.0479	69	21.9634	119	37.8789	169	53.7944
20	6.3662	70	22.2817	120	38.1972	170	54.1127
21	6.6845	71	22.6000	121	38.5155	171	54.4310
22	7.0028	72	22.9183	122	38.8338	172	54.7493
23	7.3211	73	23.2366	123	39.1521	173	55.0676
24	7.6394	74	23.5549	124	39.4704	174	55.3859
25	7.9577	75	23.8732	125	39.7887	175	55.7042
26	8.2761	76	24.1916	126	40.1070	176	56.0225
27	8.5944	77	24.5099	127	40.4254	177	56.3408
28	8.9127	78	24.8282	128	40.7437	178	56.6592
29	9.2310	79	25.1465	129	41.0620	179	56.9775
30	9.5493	80	25.4648	130	41.3803	180	57.2958
31	9.8676	81	25.7831	131	41.6986	181	57.6141
32	10.1859	82	26.1014	132	42.0169	182	57.9324
33	10.5042	83	26.4197	133	42.3352	183	58.2507
34	10.8225	84	26.7380	134	42.6535	184	58.5690
35	11.1408	85	27.0563	135	42.9718	185	58.8873
36	11.4592	86	27.3747	136	43.2901	186	59.2056
37	11.7775	87	27.6930	137	43.6085	187	59.5239
38	12.0958	88	28.0113	138	43.9268	188	59.8423
39	12.4141	89	28.3296	139	44.2451	189	60.1606
40	12.7324	90	28.6479	140	44.5634	190	60.4789
41	13.0507	91	28.9662	141	44.8817	191	60.7972
42	13.3690	92	29.2845	142	45.2000	192	61.1155
43	13.6873	93	29.6028	143	45.5183	193	61.4338
44	14.0056	94	29.9211	144	45.8366	194	61.7521
45	14.3239	95	30.2394	145	46.1549	195	62.0704
46	14.6423	96	30.5577	146	46.4732	196	62.3887
47	14.9606	97	30.8761	147	46.7916	197	62.7070
48	15,2789	98	31.1944	148	47.1099	198	63.0254
49	15,5972	99	31.5127	149	47.4282	199	63.3437
50	15.9155	100	31.8310	150	47.7465	200	63.6620

Reciprocals of Numbers from 1 to 1000

No.	Reciprocal	No.	Reciprocal	No.	Reciprocal	No.	Reciprocal
1	1.00000000	51	.01960784	101	.00990099	151	.00662252
2	.50000000	52	.01923077	102	.00980392	152	.00657895
3	.33333333	53	.01886792	103	.00970874	153	.00653595
4	.25000000	54	.01851852	104	.00961538	154	.00649351
5	.20000000	55	.01818182	105	.00952381	155	.00645161
6	.16666667	56	.01785714	106	.00943396	156	.00641026
7	.14285714	57	.01754386	107	.00934579	157	.00636943
8	.12500000	58	.01724138	108	.00925926	158	.00632911
9	.11111111	59	.01694915	109	.00917431	159	.00628931
10	.10000000	60	.01666667	110	.00909091	160	.00625000
11	.09090909	61	.01639344	111	.00900901	161	.00621118
12	.08333333	62	.01612903	112	.00892857	162	.00617284
13	.07692308	63	.01587302	113	.00884956	163	.00613497
14	.07142857	64	.01562500	114	.00877193	164	.00609756
15	.06666667	65	.01538461	115	.00869565	165	.00606061
16	.06250000	66	.01515151	116	.00862069	166	.00602410
17	.05882353	67	.01492537	117	.00854701	167	.00598802
18	.05555556	68	.01470588	118	.00847458	168	.00595238
19	.05263158	69	.01449275	119	.00840336	169	.00591716
20	.05000000	70	.01428571	120	.00833333	170	.00588235
21	.04761905	71	.01408451	121	.00826446	171	.00584795
22	.04545455	72	.01388889	122	.00819672	172	.00581395
23	.04347826	73	.01369863	123	.00813008	173	.00578035
24	.04166667	74	.01351351	124	.00806452	174	.00574713
25	.04000000	75	.01333333	125	.00800000	175	.00571429
26	.03846154	76	.01315789	126	.00793651	176	.00568182
27	.03703704	77	.01298701	127	.00787402	177	.00564972
28	.03571429	78	.01282051	128	.00781250	178	.00561798
29	.03448276	79	.01265823	129	.00775194	179	.00558659
30	.03333333	80	.01250000	130	.00769231	180	.00555556
31	.03225806	81	.01234568	131	.00763359	181	.00552486
32	.03125000	82	.01219512	132	.00757576	182	.00549451
33	.03030303	83	.01204819	133	.00751880	183	.00546448
34	.02941176	84	.01190476	134	.00746269	184	.00543478
35	.02857143	85	.01176471	135	.00740741	185	.00540540
36	.02777778	86	.01162791	136	.00735294	186	.00537634
37	.02702703	87	.01149425	137	.00729927	187	.00534759
38	.02631579	88	.01136364	138	.00724638	188	.00531914
39	.02564103	89	.01123595	139	.00719424	189	.00529100
40	.02500000	90	.01111111	140	.00714286	190	.00526316
41	.02439024	91	.01098901	141	.00709220	191	.00523560
42	.02380952	92	.01086956	142	.00704225	192	.00520833
43	.02325581	93	.01075269	143	.00699301	193	.00518135
44	.02272727	94	.01063830	144	.00694444	194	.00515464
45	.02222222	95	.01052632	145	.00689655	195	.00512820
46	.02173913	96	.01041667	146	.00684931	196	.00510204
47	.02127660	97	.01030928	147	.00680272	197	.00507614
48	.02083333	98	.01020408	148	.00675676	198	.00505051
49	.02040816	99	.01010101	149	.00671141	199	.00502513
50	.02000000	100	.01000000	150	.00666667	200	.00500000

RECIPROCALS OF NUMBERS FROM 1 TO 1000

No.	Reciprocal	No.	Reciprocal	No.	Reciprocal	No.	Reciprocal
201	.00497512	251	.00398406	301	.00332226	351	.00284900
202	.00495049	252	.00396825	302	.00331126	352	.00284091
203	.00492611	253	.00395257	303	.00330033	353	.00283286
204	.00490196	254	.00393701	304	.00328947	354	.00282486
205	.00487805	255	.00392157	305	.00327869	355	.00281690
206	.00485437	256	.00390625	306	.00326797	356	.00280899
207	.00483092	257	.00389105	307	.00325733	357	.00280112
208	.00480769	258	.00387597	308	.00324675	358	.00279330
209	.00478469	259	.00386100	309	.00323625	359	.00278551
210	.00476190	260	.00384615	310	.00322581	360	.00277778
211	.00473934	261	.00383142	311	.00321543	361	.00277008
212	.00471698	262	.03381679	312	.00320513	362	.00276243
213	.00469484	263	.00380228	313	.00319489	363	.00275482
214	.00467290	264	.00378788	314	.00318471	364	.00274725
215	.00465116	265	.00377358	315	.00317460	365	.00273973
216	.00462963	266	.00375940	316	.00316456	366	.00273224
217	.00460829	267	.00374532	317	.00315457	367	.00272480
218	.00458716	268	.00373134	318	.00314465	368	.00271739
219	.00456621	269	.00371747	319	.00313480	369	.00271003
220	.00454545	270	.00370370	320	.00312500	370	.00270270
221	.00452489	271	.00369004	321	.00311526	371	.00269542
222	.00450450	272	.00367647	322	.00310559	372	.00268817
223	.00448430	273	.00366300	323	.00309597	373	.00268096
224	.00446429	274	.00364963	324	.00308642	374	.00267380
225	.00444444	275	.00363636	325	.00307692	375	.00266667
226	.00442478	276	.00362319	326	.00306748	376	.00265957
227	.00440529	277	.00361011	327	.00305810	377	.00265252
228	.00438596	278	.00359712	328	.00304878	378	.00264550
229	.00436681	279	.00358423	329	.00303951	379	.00263852
230	.00434783	280	.00357143	330	.00303030	380	.00263158
231	.00432900	281	.00355872	331	.00302115	381	.00262467
232	.00431034	282	.00354610	332	.00301205	382	.00261780
233	.00429184	283	.00353357	333	.00300300	383	.00261097
234	.00427350	284	.00352113	334	.00299401	384	.00260417
235	.00425532	285	.00350877	335	.00298507	385	.00259740
236	.00423729	286	.00349650	336	.00297619	386	.00259067
237	.00421941	287	.00348432	337	.00296736	387	.00258398
238	.00420168	288	.00347222	338	.00295858	388	.00257732
239	.00418410	289	.00346021	339	.00294985	389	.00257069
240	.00416667	290	.00344828	340	.00294118	390	.00256410
241	.00414938	291	.00343643	341	.00293255	391	.00255754
242	.00413223	292	.00342466	342	.00292398	392	.00255102
243	.00411523	293	.00341297	343	.00291545	393	.00254453
244	.00409836	294	.00340136	344	.00290698	394	.00253807
245	.00408163	295	.00338983	345	.00289855	395	.00253165
246	.00406504	296	.00337838	346	.00289017	396	.00252525
247	.00404858	297	.00336700	347	.00288184	397	.00251889
248	.00403226	298	.00335570	348	.00287356	398	.00251256
249	.00401606	299	.00334448	349	.00286533	399	.00250627
250	.00400000	300	.00333333	350	.00285714	400	.00250000

RECIPROCALS OF NUMBERS FROM 100 TO 1000

No.	Reciprocal	No.	Reciprocal	No.	Reciprocal	No.	Reciprocal
401	.00249377	451	.00221729	501	.00199601	551	.00181488
402	.00248756	452	.00221239	502	.00199203	552	.00181159
403	.00248139	453	.00220751	503	.00198807	553	.00180832
404	.00247525	454	.00220264	504	.00198413	554	.00180505
405	.00246914	455	.00219780	505	.00198020	555	.00180180
406	.00246305	456	.00219298	506	.00197628	556	.00179856
407	.00245700	457	.00218818	507	.00197239	557	.00179533
408	.00245098	458	.00218341	508	.00196850	558	.00179211
409	.00244499	459	.00217865	509	.00196464	559	.00178891
410	.00243902	460	.00217391	510	.00196078	560	.00178571
411	.00243309	461	.00216920	511	.00195695	561	.00178253
412	.00242718	462	.00216450	512	.00195312	562	.00177936
413	.00242131	463	.00215983	513	.00194932	563	.00177620
414	.00241546	464	.00215517	514	.00194552	564	.00177305
415	.00240964	465	.00215054	515	.00194175	565	.00176991
416	.00240385	466	.00214592	516	.00193798	566	.00176678
417	.00239808	467	.00214133	517	.00193424	567	.00176367
418	.00239234	468	.00213675	518	.00193050	568	.00176056
419	.00238663	469	.00213220	519	.00192678	569	.00175747
420	.00238095	470	.00212766	520	.00192308	570	.00175439
421	.00237530	471	.00212314	521	.00191939	571	.00175131
422	.00236967	472	.00211864	522	.00191571	572	.00174825
423	.00236407	473	.00211416	523	.00191205	573	.00174520
424	.00235849	474	.00210970	524	.00190840	574	.00174216
425	.00235294	475	.00210526	525	.00190476	575	.00173913
426	.00234742	476	.00210084	526	.00190114	576	.00173611
427	.00234192	477	.00209644	527	.00189753	577	.00173310
428	.00233645	478	.00209205	528	.00189394	578	.00173010
429	.00233100	479	.00208768	529	.00189036	579	.00172712
430	.00232558	480	.00208333	530	.00188679	580	.00172414
431	.00232019	481	.00207900	531	.00188324	581	.00172117
432	.00231481	482	.00207469	532	.00187970	582	.00171821
433	.00230947	483	.00207039	533	.00187617	583	.00171527
434	.00230415	484	.00206612	534	.00187266	584	.00171233
435	.00229885	485	.00206186	535	.00186916	585	.00170940
436	.00229358	486	.00205761	536	.00186567	586	.00170648
437	.00228833	487	.00205339	537	.00186220	587	.00170358
438	.00228310	488	.00204918	538	.00185874	588	.00170068
439	.00227790	489	.00204499	538	.00185528	589	.00169779
440	.00227273	490	.00204082	540	.00185185	590	.00169491
441	.00226757	491	.00203666	541	.00184843	591	.00169205
442	.00226244	492	.00203252	542	.00184502	592	.00168919
443	.00225734	493	.00202840	543	.00184162	593	.00168634
444	.00225225	494	.00202429	544	.00183823	594	.00168350
445	.00224719	495	.00202020	545	.00183486	595	.00168067
446	.00224215	496	.00201613	546	.00183150	596	.00167785
447	.00223714	497	.00201207	547	.00182815	597	.00167504
448	.00223214	498	.00200803	548	.00182482	598	.00167224
449	.00222717	499	.00200401	549	.00182149	599	.00166945
450	.00222222	500	.00200000	550	.00181818	600	.00166667

Reciprocals of Numbers from 1 to 1000

No.	Reciprocal	No.	Reciprocal	No.	Reciprocal	No.	Reciprocal
601	.00166389	651	.00153610	701	.00142653	751	.00133156
602	.00166113	652	.00153374	702	.00142450	752	.00132979
603	.00165837	653	.00153140	703	.00142247	753	.00132802
604	.00165563	654	.00152905	704	.00142045	754	.00132626
605	.00165289	655	.00152672	705	.00141844	755	.00132450
606	.00165016	656	.00152439	706	.00141643	756	.00132275
607	.00164745	657	.00152207	707	.00141443	757	.00132100
608	.00164474	658	.00151975	708	.00141243	758	.00131926
609	.00164204	659	.00151745	709	.00141044	759	.00131752
610	.00163934	660	.00151515	710	.00140845	760	.00131579
611	.00163666	661	.00151286	711	.00140647	761	.00131406
612	.00163399	662	.00151057	712	.00140449	762	.00131234
613	.00163132	663	.00150830	713	.00140252	763	.00131062
614	.00162866	664	.00150602	714	.00140056	764	.00130890
615	.00162602	665	.00150376	715	.00139860	765	.00130719
616	.00162338	666	.00150150	716	.00139665	766	.00130548
617	.00162075	667	.00149925	717	.00139470	767	.00130378
618	.00161812	668	.00149701	718	.00139276	768	.00130208
619	.00161551	669	.00149477	719	.00139082	769	.00130039
620	.00161290	670	.00149254	720	.00138889	770	.00129870
621	.00161031	671	.00149031	721	.00138696	771	.00129702
622	.00160772	672	.00148809	722	.00138504	772	.00129534
623	.00160514	673	.00148588	723	.00138313	773	.00129366
624	.00160256	674	.00148368	724	.00138121	774	.00129199
625	.00160000	675	.00148148	725	.00137931	775	.00129032
626	.00159744	676	.00147929	726	.00137741	776	.00128866
627	.00159490	677	.00147710	727	.00137552	777	.00128700
628	.00159236	678	.00147493	728	.00137363	778	.00128535
629	.00158982	679	.00147275	729	.00137174	779	.00128370
630	.00158730	680	.00147059	730	.00136986	780	.00128205
631	.00158479	681	.00146843	731	.00136799	781	.00128041
632	.00158228	682	.00146628	732	.00136612	782	.00127877
633	.00157978	683	.00146413	733	.00136426	783	.00127714
634	.00157729	684	.00146199	734	.00136240	784	.00127551
635	.00157480	685	.00145985	735	.00136054	785	.00127388
636	.00157233	686	.00145773	736	.00135870	786	.00127226
637	.00156986	687	.00145560	737	.00135685	787	.00127065
638	.00156740	688	.00145349	738	.00135501	788	.00126904
639	.00156494	689	.00145137	739	.00135318	789	.00126743
640	.00156250	690	.00144927	740	.00135135	790	.00126582
641	.00156006	691	.00144718	741	.00134953	791	.00126422
642	.00155763	692	.00144509	742	.00134771	792	.00126263
643	.00155521	693	.00144300	743	.00134589	793	.00126103
644	.00155279	694	.00144092	744	.00134409	794	.00125945
645	.00155039	695	.00143885	745	.00134228	795	.00125786
646	.00154799	696	.00143678	746	.00134048	796	.00125628
647	.00154559	697	.00143472	747	.00133869	797	.00125470
648	.00154321	698	.00143266	748	.00133690	798	.00125313
649	.00154083	699	.00143061	749	.00133511	799	.00125156
650	.00153846	700	.00142857	750	.00133333	800	.00125000

RECIPROCALS OF NUMBERS FROM 1 TO 1000

No.	Reciprocal	No.	Reciprocal	No.	Reciprocal	No.	Reciprocal
801	.00124844	851	.00117509	901	.00110988	951	.00105152
802	.00124688	852	.00117371	902	.00110865	952	.00105042
803	.00124533	853	.00117233	903	.00110742	953	.00104932
804	.00124378	854	.00117096	904	.00110619	954	.00104822
805	.00124224	855	.00116959	905	.00110497	955	.00104712
806	.00124069	856	.00116822	906	.00110375	956	.00104602
807	.00123916	857	.00116686	907	.00110254	957	.00104493
808	.00123762	858	.00116550	908	.00110132	958	.00104384
809	.00123609	859	.00116414	909	.00110011	959	.00104275
810	.00123457	860	.00116279	910	.00109890	960	.00104167
811	.00123305	861	.00116144	911	.00109769	961	.00104058
812	.00123153	862	.00116009	912	.00109649	962	.00103950
813	.00123001	863	.00115875	913	.00109529	963	.00103842
814	.00122850	864	.00115741	914	.00109409	964	.00103734
815	.00122699	865	.00115607	915	.00109290	965	.00103627
816	.00122549	866	.00115473	916	.00109170	966	.00103520
817	.00122399	867	.00115340	917	.00109051	967	.00103413
818	.00122249	868	.00115207	918	.00108932	968	.00103306
819	.00122100	869	.00115075	919	.00108814	969	.00103199
820	.00121951	870	.00114942	920	.00108696	970	.00103093
821	.00121803	871	.00114811	921	.00108578	971	.00102987
822	.00121654	872	.00114679	922	.00108460	972	.00102881
823	.00121507	873	.00114547	923	.00108342	973	.00102775
824	.00121359	874	.00114416	924	.00108225	974	.00102669
825	.00121212	875	.00114286	925	.00108108	975	.00102564
826	.00121065	876	.00114155	926	.00107991	976	.00102459
827	.00120919	877	.00114025	927	.00107875	977	.00102354
828	.00120773	878	.00113895	928	.00107759	978	.00102250
829	.00120627	879	.00113766	929	.00107643	979	.00102145
830	.00120482	880	.00113636	930	.00107527	980	.00102041
831	.00120337	881	.00113507	931	.00107411	981	.00101937
832	.00120192	882	.00113379	932	.00107296	982	.00101833
833	.00120048	883	.00113250	933	.00107181	983	.00101729
834	.00119904	884	.00113122	934	.00107066	984	.00101626
835	.00119760	885	.00112994	935	.00106952	985	.00101523
836	.00119617	886	.00112867	936	.00106838	986	.00101420
837	.00119474	887	.00112740	937	.00106724	987	.00101317
838	.00119332	888	.00112613	938	.00106610	988	.00101215
839	.00119189	889	.00112486	939	.00106496	989	.00101112
840	.00119048	890	.00112360	940	.00106383	990	.00101010
841	.00118906	891	.00112233	941	.00106270	991	.00100908
842	.00118765	892	.00112108	942	.00106157	992	.00100806
843	.00118624	893	.00111982	943	.00106044	993	.00100705
844	.00118483	894	.00111857	944	.00105932	994	.00100604
845	.00118343	895	.00111732	945	.00105820	995	.00100502
846	.00118203	896	.00111607	946	.00105708	996	.00100402
847	.00118064	897	.00111483	947	.00105597	997	.00100301
848	.00117924	898	.00111359	948	.00105485	998	.00100200
849	.00117786	899	.00111235	949	.00105374	999	.00100100
850	.00117647	900	.00111111	950	.00105263	1000	.00100000

SECTION XXV

AUTOMOTIVE DATA

Considerable information relating to automotive practice will be found in other sections, as it seems best to put S.A.E. threads, bolts, nuts, splined and serrated shafts, steels, etc., with other data on the same subject. Some of this was formerly given in this section but has been placed elsewhere with similar data to make it more easily available to all. This section is entirely automotive material although it by no means represents all the information on automotive subjects.

AUTOMOBILE ENGINE PISTONS

Aluminum Alloy

This simply outlines general shop products as a guide in making replacement parts. Definite clearances used by automobile makers are given later.

The main advantage of the aluminum or other light-alloy piston lies in its light weight, which is approximately half that of cast iron, on the average. The head conducts heat more rapidly than cast iron, but the metal is not so good for a wearing surface. Ford uses a very light steel-alloy piston.

Clearance.—Many aluminum pistons have the skirt split at a slight angle to allow for expansion; the angle prevents leaving a ridge in the cylinder. The clearance is about the same as for cast iron, 0.001 inch per inch of cylinder diameter, for water-cooled engines. The clearance of the top land is 0.005 inch, the second and third, 0.003 to 0.004 inch per inch of diameter.

Ring Fits.—The clearance recommended for the piston rings in the groove is from 0.001 to 0.0015 inch. This can be measured with a feeler. The gap in the ring is the same as for cast-iron pistons.

Machining.—Aluminum pistons are usually rough turned without lubricant at from 400 to 500 surface feet per minute. A cut $\frac{3}{32}$ inch deep and a feed of 0.025 inch per revolution are good practice. The tool should be keen and have about 15-degree top rake, about the same side clearance, and 5-degree face clearance with a slightly rounded corner. Diamonds are sometimes used in finishing.

Grooves are cut with a parting tool as close to the tool post as possible and with plenty of side clearance. Top rake is about 15 degrees, and front clearance about 5 degrees. For roughing the grooves, run at 300 feet per minute, and leave 0.005 inch on each side for finishing. Stone the tool carefully, and run at 500 feet per minute.

Piston-Pin Holes.—Piston- or wrist-pin holes should be bored with from 0.003 to 0.005 inch left for reaming.

Grinding is recommended for finishing, a 40-crystolon wheel or its equivalent being used with a lubricant of one part kerosene and two parts mineral lard oil. If finished with a tool, use 500 feet per minute and 0.010- to 0.015-inch feed per revolution with tool point flat enough to cover feed.

Gap or Clearance between Ends.—Piston rings should clear the cylinder bore and have a proper gap between the ends. It is better to have gaps too large than too small. Rings having an angle cut should have 0.002-inch gap per inch of diameter for the top ring, half this for the second ring, and about 0.00075 inch per inch of diameter for the third ring. Some fit the lower rings and rings in the skirt with ends touching, but a slight gap is more common practice.

With rings having a step cut instead of an angle cut, a greater gap between the ends is permissible, as the ends lap by each other.

For air-cooled motors some recommend about double the gap clearance given above.

Cast Iron

Clearance in Cylinder Bore.—A clearance of 0.001 inch for each inch of cylinder diameter may be called standard practice for piston skirts. For taxi, truck and tractor motors many recommend an extra 0.001 inch on the total, that is, a 4-inch piston should have a clearance of 0.004 plus an extra 0.001 or 0.005 inch total clearance. Some air-cooled motors require a little more clearance.

The clearance refers to the diameter of the skirt of the piston below the lowest ring in the head. The "lands" between the rings are smaller in diameter because of the greater heat and expansion due to the piston head. The top land should have 0.0035 inch clearance per inch of diameter, while the second land should have a clearance of 0.002 inch per inch of diameter.

If feelers are used to measure the clearance between the piston and cylinder wall, instead of inside and outside micrometers, an allowance must be made for the stiffness of the feeler or its resistance to bending. It is recommended that 0.001 inch be allowed for this, that is, if a feeler 0.002 inch goes in, the real clearance is 0.001 greater or 0.003 inch.

Standard Oversize Pistons and Rings

Standard oversize pistons and rings are recommended by makers of passenger car, truck, motorboat, tractor, industrial, and airplane engines. These are oversizes of 0.003, 0.005, 0.010, 0.015, and 0.030 inch. Some tractor and other heavy-duty engines also suggest 0.040 inch. If larger sizes are considered necessary, they are to be held in multiples of 0.010 inch.

Piston rings are held to the same oversizes except that the 0.003 inch is omitted.

FITS AND CLEARANCES OF PRATT & WHITNEY AIRCRAFT ENGINES
Wasp H-1 and Hornet E

Description of Clearance	Minimum	Maximum	Replacement
Pin, knuckle—insert, knuckle pin	0.0005T	0.002T	0.004
Shaft, propeller—bearing, bronze	0.003L	0.005L	0.006
Tappet—roller, tappet (side clearance)	0.008L	0.020L	
Tappet—guide, tappet	Light hand push		0.003 fit at room temp.
Piston and cylinder clearance—Wasp H-1	0.020L	0.024L	0.030
Piston and cylinder clearance—Hornet E	0.028L	0.032L	0.038
Link rod—bushing, piston pin	0.0015T	0.0045T	*
Piston pin and piston	Light hand push		0.003 fit at room temp.
Bearing, master rod—master rod	0.0015T	0.0035T	*
Crankpin—bearing, master rod hornet	0.005L	0.0055L	0.0075
Crankpin—bearing, master rod wasp	0.0045L	0.005L	0.0075
Master rod bearing and crankshaft—end clearance	0.010	0.014	0.020
Master rod and link rod—end clearance	0.006L	0.008L	0.014
Pin, knuckle—master rod	0.0007T	0.0015T	*
Pin, knuckle—bushing, link rod	0.0015L	0.0025L	0.004
Link rod—bushing, link rod	0.0015T	0.0045T	*
Bearing, rear main—liner, crankcase rear main	0.0002L	0.0017L	0.004
Bearing, roller—hub, bell gear	0.0012T	0.000	
Bearing, rear main—crankshaft	0.0012T	0.0002L	0.001
Impeller—blower	0.025L	0.035L	0.045
Generator drive, backlash	0.004	0.012	
Cup, valve rocker—rocker, valve	0.000	0.0025T	*
Pin, tappet roller—tappet	0.000	0.002L	0.003
Roller, tappet—pin, tappet roller	0.0005L	0.0025L	0.004
Bushing, valve rocker shaft—head, cylinder (large end)	0.001T	0.004T	*
Cylinder barrel—max. taper or out of round			0.006
Rear bearing, int. shaft—outer liner, rear bearing	0.0008L	0.002L	0.002
Rear bearing, int. shaft—inner liner, rear bearing	0.0005T	0.0002L	0.001
Shaft, inter.—inner liner, int. shaft rear bearing	0.0005T	0.0005L	0.002
Front bearing, int. shaft—bearing support	0.0000	0.0009L	0.0015
Front bearing, int. shaft—shaft, int.	0.0004T	0.0002L	0.001
Crankshaft—hub, bell gear O.D.	0.003L	0.015L	
Crankshaft—hub, bell gear I.D.	0.055L	0.069L	
Crankshaft—hub, bell gear W.D.	0.0015L	0.0005T	
Hub, pinion—shaft propeller O.D.	0.003L	0.015L	
Hub, pinion—shaft propeller I.D.	0.0035L	0.0049L	
Hub, pinion—shaft propeller W.D.	0.001L	0.0005T	
Gear, pinion backlash	0.006	0.012	0.018
Pinion gear—end clearance	0.010	0.016	0.020
Bearing, bronze—crankshaft	0.002T	0.004T	*
Bearing support—crankcase, main	0.003T	0.001L	
Gear, pinion—bushing, pinion red. gear	0.001T	0.0025T	

NOTE.—These are average service fits recommended by the makers. The letters L and T mean loose and tight by the amounts shown.

TYPICAL CLEARANCES IN AUTOMOBILE ENGINES

	Inches
Pistons:	
Top land	0.0165 to 0.026
Bottom of skirt	0.0005 to 0.0027
Piston rings—average gap	0.010 to 0.014
Piston pin	0.0001 to 0.0005
Connecting rod:	
Crankpin bearing	0.0010 to 0.0020
Side play	0.0050 to 0.0157
Crankshaft, main bearings	0.0010 to 0.0030
Valve stem in guide	0.0015 to 0.0025
Valve-tappet clearance:	
Intake	0.006 to 0.015 hot
Exhaust	0.008 to 0.016 hot

FITS AND TOLERANCE
FORD 85 HORSE-POWER ENGINE

	Inches
Cylinder block bore	3.0625 to 3.0635
Piston diameter	3.062 to 3.060
Fit	0.0005 to 0.0035
Main bearing insert diameter	2.399 to 2.4005
Main bearing diameter	2.399 to 2.398
Fit	0.000 to 0.0025
Connecting-rod bearing bore	2.2195 to 2.2200
Connecting-rod insert (outside diameter)	2.218 to 2.217
Fit	0.0015 to 0.0030
Piston wrist-pin bore	0.7503 to 0.7506
Wrist-pin	0.7504 to 0.7501
Fit	0.0003 to 0.0009
Connecting-rod wrist-pin bore	0.7503 to 0.7506
Wrist pin	0.7504 to 0.7501
Fit	0.0001 to 0.0005
Piston ring, first groove width	0.0940 to 0.0950
Piston ring, compression width	0.0920 to 0.0915
Fit	0.0020 to 0.0035
Piston ring, second groove width	0.0935 to 0.0945
Piston ring, compression width	0.0920 to 0.0915
Fit	0.0015 to 0.0030
Piston ring, oil-groove width	0.1565 to 0.1575
Piston ring, oil width	0.1550 to 0.1545
Fit	0.0005 to 0.0030
Connecting-rod insert, inside diameter	1.998 to 1.9995
Connecting-rod crankshaft bearing	1.999 to 1.998
Fit	0.001 to 0.0015
Total clearance between connecting-rod bearing bore and crankshaft bearing	0.0005 to 0.0045

FITS AND TOLERANCE FOR LINCOLN ZEPHYR ENGINE

	INCHES
Main bearing	0.0015 to 0.0035 loose
Crankpins	0.0015 to 0.0030 loose
Cam bearings	0 0015 to 0.0030 loose
Tappet in cylinders	0.0005 to 0.0015 loose
Valve in guide	0.0015 to 0 0035 loose
Wrist pins in connecting rods	0.0005 to 0.0001 tight
Wrist pins in piston	0.0003 to 0.0009 loose
Piston in cylinder-cylinder bore	2.750 diameter

Pistons are machined in sizes varying by 0.0005 inch and selected for the cylinder bore. Each piston must require 5 to 8 pounds pull in its cylinder with a 0.002-inch shim between piston and cylinder wall.

SECTION XXVI

RAILROAD SHOP DATA

STANDARD CLASSIFICATION OF REPAIRS TO LOCOMOTIVES AND TENDERS

TO BE USED, BEGINNING JUNE 1, 1918, BY ALL CARRIERS FOR REPORTING REPAIRS TO LOCOMOTIVES MADE AT THEIR VARIOUS SHOPS AND ROUNDHOUSES

Since nearly all railroad shop work is the repairing of motive power and rolling stock it is of interest to know just how these repairs are classified. The designation of locomotive repairs as outlined by the United States Railroad Administration in 1918 is still followed. There are five classes of repairs as follows:

Class 1

New boiler or new back end. Flues new or reset.
Tires turned, or new.
General repairs to machinery and tender.

Class 2

New firebox, or one or more shell courses, or roof sheet.
Flues new or reset.
Tires turned or new.
General repairs to machinery and tender.

Class 3

Flues all new or reset (superheater flues may be excepted).
Necessary repairs to firebox and boiler.
Tires turned or new.
General repairs to machinery and tender.

Class 4

Flues part or full set.
Light repairs to boiler or firebox.
Tires turned or new.
Necessary repairs to machinery and tender.

Class 5

Tires turned or new.

Necessary repairs to boiler, machinery, and tender, including one or more pairs of driving-wheel bearings refitted.

General repairs to machinery will include driving wheels removed, tires turned or changed, journals turned, if necessary, and all driving boxes and rods overhauled for a full term of service.

Running repairs unclassified.

Suffix A to any class of repairs will indicate that the repairs are required on account of accident.

Suffix B will show the initial application of stoker.

Suffix C will indicate the initial application of superheater.

Suffix D will indicate the initial application of outside-valve gear.

Suffix E will indicate locomotive was converted from compound to simple, or from one type to another.

Mallet locomotives will be indicated by a star following classification.

Locomotives receiving class 1, 2, or 3 repairs must be put in condition to perform a full term of service in the district and class of service in which they are to be used.

Locomotives receiving class 4 repairs must be put in condition to perform not less than one-half term of service in the district and class of service in which they are to be used.

Locomotives receiving class 5 repairs must be put in condition to perform not less than one-fourth term of service in the district and class of service in which they are to be used.

Much information that can be applied to railroad work will be found in nearly every section of this handbook, and it seems best to put only that which pertains directly to railroads in this section.

BORING AND TURNING TIRES

Tire turning and boring vary on different railroads. Much of this difference is due to the equipment. Tire steel is very hard, and only machines that are rigid and powerful can cut it at high speeds. A few examples of tire boring and turning from several well-known shops are given in Tables 1 and 2. By the use of modern boring mills and special tools, one road rough-bores tires at 292 and finishes at 320 feet per minute. Tire turning is much slower because of the way in which mounted tires are held and driven.

TABLE 1.—CONDENSED TIRE BORING TOOL DATA

Size of Tool Body, in Inches	Top Rake of Tool, in Degrees	Clearance at Point, in Degrees	Cutting Speed, Feet per Minute		Feed per Revolution	
			Roughing	Finishing	Roughing	Finishing
$1\frac{1}{4} \times 1\frac{1}{4}$	8	6	25	25	$\frac{1}{4}$	$\frac{1}{2}$
$1\frac{1}{2} \times 1\frac{1}{2}$	12	10	15	15	$\frac{1}{2}$	$\frac{1}{2}$
$1 \times 1\frac{1}{2}$	6	6	14	12	$\frac{1}{8}$	$\frac{1}{8}$
$1\frac{1}{4} \times 1\frac{1}{4}$	18	5	23	23	$\frac{5}{32}$	$\frac{5}{16}$
$1\frac{1}{4} \times 1\frac{1}{4}$	8–10	7	40	40	$\frac{1}{8}$	$\frac{1}{8}$
1×2	5	7	55	50	$\frac{1}{8}$	$\frac{3}{8}$
1×1	15	6	28	28	$\frac{1}{16}$	$\frac{1}{16}$
$1\frac{1}{2} \times 3$	6	4	30	30	$\frac{1}{16}$	$\frac{1}{16}$
$1\frac{1}{4} \times 1\frac{1}{4}$	2	7	30	30	$\frac{3}{8}$	$\frac{3}{8}$

Compare the top rake, side clearance, speeds, and feeds to appreciate the extreme variations.

Typical tire boring and turning tools are shown in Figs. 1 and 2. The speeds and feeds are shown in the tables. On modern wheel

TABLE 2.—TIRE TURNING DATA

Size of Tool Body in Inches	Top Rake of Tool, Degrees	Clearance at Point, Degrees	Cutting Speed Feet per Minute		Feed per Revolution in Inches, Roughing
			Roughing	Finishing	
2½ × 2½	5	3½	17	17	⅜
2 × 3	12	15	16–18	18	½
1½ × 3	2	4	11	11	¼ × ⅜
1½ × 3	8	6	16	12	½
1½ × 3	5	5	15	15	⅜
1½ × 4	2	7	50	45	½
1½ × 3	12	6	15	10	5/16
1½ × 3	2	5	15	17	⅜

lathes a roughing feed of ½ inch is common, the finish being done with form tools as shown. Figure 2 shows the tools used by a prominent railroad, which conform with the standards of the Association of American Railroads, formerly the Railway Master Mechanics. The form tools must be made in pairs, for right and left wheels. Both flanges can be roughed with the same tool, but two tools are used in finishing the tread, one for the flange and the other for rounding the outer edge. Two finishing tools are shown.

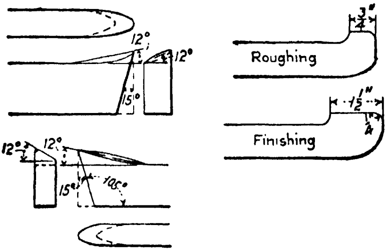


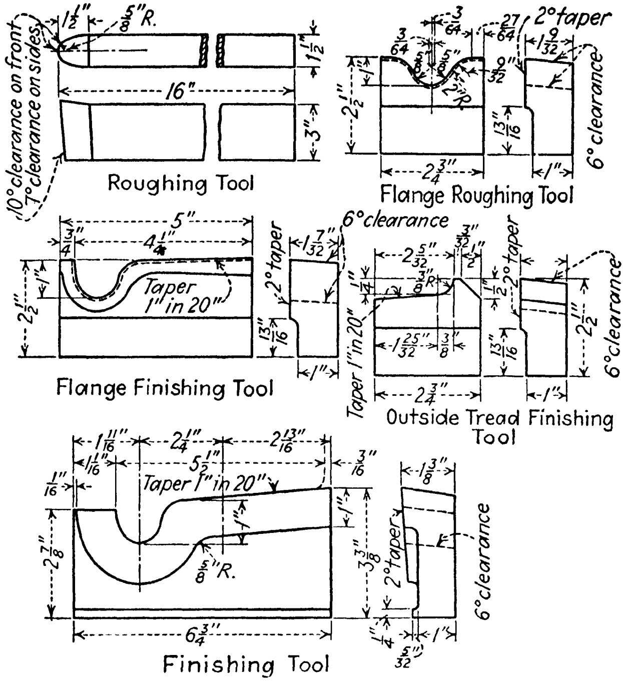
FIG. 1.—Tire Boring Tools

General Instructions for Shimming Locomotive Wheel Centers

The minimum diameter for a driving-wheel center is usually at dimension *A*, and the maximum diameter at dimension *B*, Fig. 3.

Wheel centers that are ⅛ inch or less in diameter out of round may be corrected by the use of shims which are furnished in thicknesses of 1/64, 1/32, 1/16, and 3/32 inch.

Not more than two thicknesses of shims may be used, and when two are required, one must extend entirely around the wheel center. Shims equal in length to one-quarter of the wheel center circumference may be applied at locations *XY* or *LM*, or both, to compensate for the amount the wheels are out of round.


Roughing Tool

Flange Roughing Tool

Flange Finishing Tool

Outside Tread Finishing Tool

Finishing Tool

FIG. 2.—Roughing and Form Tools for Tire Turning

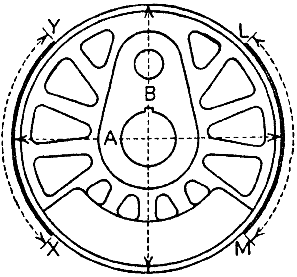


FIG. 3.—Shimming Driving-Wheel Centers

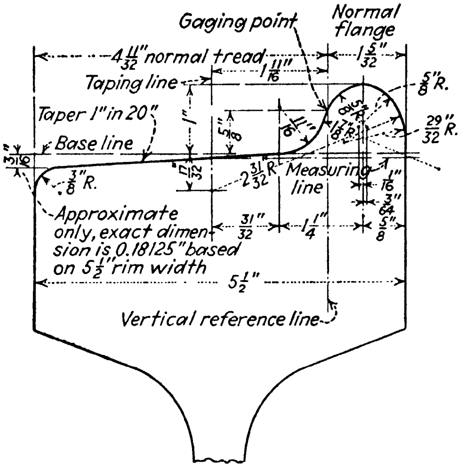


Fig. 4.—For Engine and Tender Trucks, Trailers, and Flanged Locomotive Driving Tires

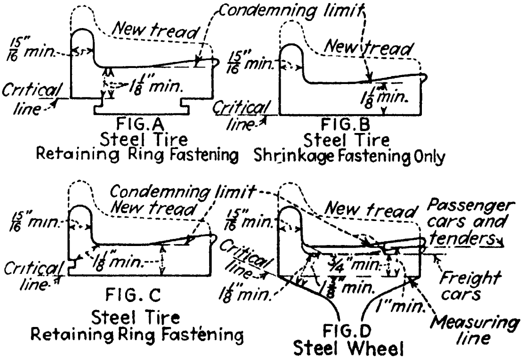


Fig. 5.—Wear Allowances of Different Types of Steel Tires; as Revised in 1923 and 1937

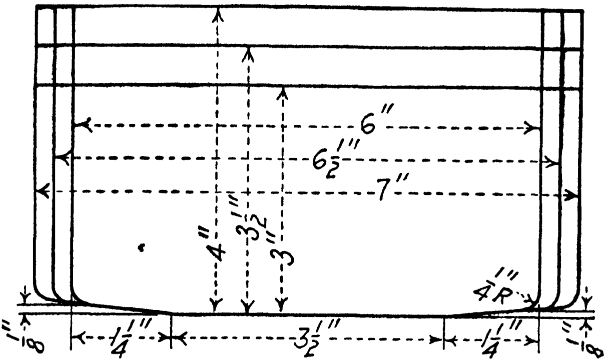


FIG. 6.—Standard Plain Tire

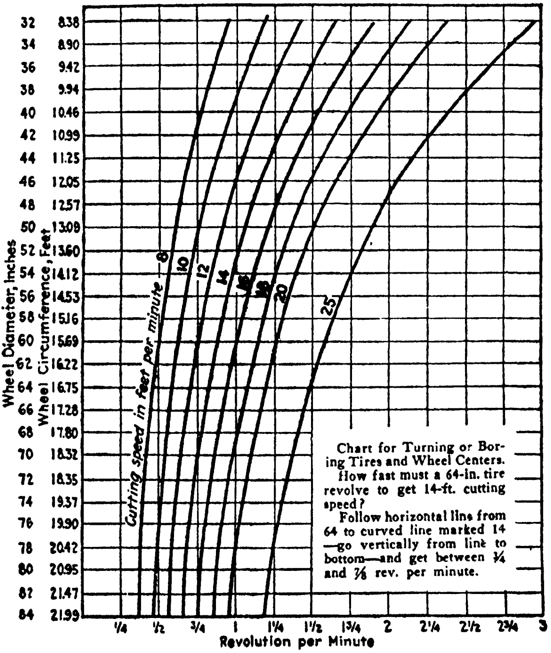


Chart for Turning or Boring Tires and Wheel Centers.

How fast must a 64-in. tire revolve to get 14-ft. cutting speed?

Follow horizontal line from 64 to curved line marked 14—go vertically from line to bottom—and get between ¾ and ⅞ rev. per minute.

FIG. 7.—Chart for Tire-Turning Speeds

Driving-wheel centers that are more than ⅛ inch diameter out of round are to be built up and trued.

Driving-wheel centers that are more than ⅛ inch diameter less than normal, when measured on their longest diameter, are to be built up and turned to normal diameter.

Truck-wheel centers are rarely out of round, but when such a condition is to exist, the above limitations and instructions for driving-wheel centers are to be followed.

Truck-wheel centers that are more than ⅛ inch diameter less than normal are to be built up and turned to normal diameter.

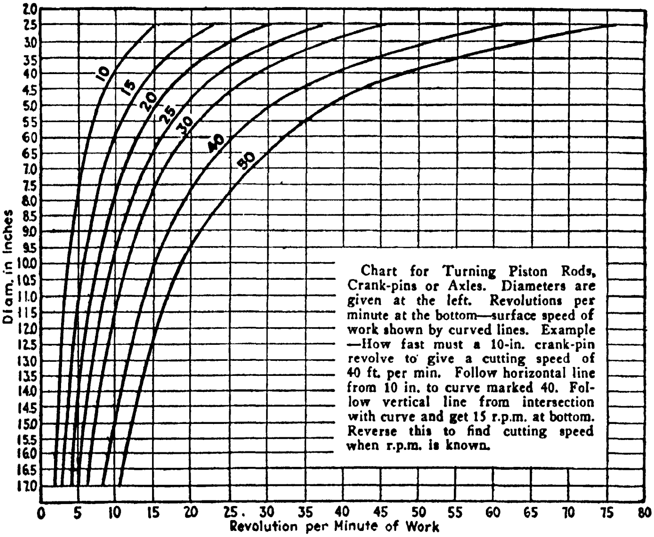


Chart for Turning Piston Rods, Crank-pins or Axles. Diameters are given at the left. Revolutions per minute at the bottom—surface speed of work shown by curved lines. Example—How fast must a 10-in. crank-pin revolve to give a cutting speed of 40 ft. per min. Follow horizontal line from 10 in. to curve marked 40. Follow vertical line from intersection with curve and get 15 r.p.m. at bottom. Reverse this to find cutting speed when r.p.m. is known.

FIG. 8.—Chart for Turning Crankpins, Axles, Etc.

Multiples of the cutting speeds shown in Fig. 8 can be easily used if necessary. A 10-inch pin, for example, must run 30 revolutions per minute to give 80 feet cutting speed.

Charts giving necessary revolutions per minute to secure the desired cutting speeds are shown in Figs. 7 and 8.

TABLE 3.—MINIMUM THICKNESS FOR DRIVING-WHEEL AND TRAILER TIRES ON STANDARD AND NARROW-GAGE LOCOMOTIVES

Weight per Axle (Weight on Drivers Divided by Number of Pairs of Driving Wheels)	Diameter of Wheel Center in Inches	Minimum Thickness, Service Limits in Inches	
		Road Service	Switching Service
30,000 pounds and under.......	44 and under	$1\frac{1}{4}$	$1\frac{1}{8}$
	Over 44 to 50	$1\frac{5}{16}$	$1\frac{3}{16}$
	Over 50 to 56	$1\frac{3}{8}$	$1\frac{1}{4}$
	Over 56 to 62	$1\frac{7}{16}$	$1\frac{3}{16}$
	Over 62 to 68	$1\frac{1}{2}$	
	Over 68 to 74	$1\frac{9}{16}$	
	Over 74	$1\frac{5}{8}$	
Over 30,000 to 35,000 pounds...	44 and under	$1\frac{5}{16}$	$1\frac{3}{16}$
	Over 44 to 50	$1\frac{3}{8}$	$1\frac{1}{4}$
	Over 50 to 56	$1\frac{7}{16}$	$1\frac{5}{16}$
	Over 56 to 62	$1\frac{1}{2}$	$1\frac{3}{8}$
	Over 62 to 68	$1\frac{9}{16}$	
	Over 68 to 74	$1\frac{5}{8}$	
	Over 74	$1\frac{11}{16}$	
Over 35,000 to 40,000 pounds...	44 and under	$1\frac{3}{8}$	$1\frac{1}{4}$
	Over 44 to 50	$1\frac{7}{16}$	$1\frac{5}{16}$
	Over 50 to 56	$1\frac{1}{2}$	$1\frac{3}{8}$
	Over 56 to 62	$1\frac{9}{16}$	$1\frac{7}{16}$
	Over 62 to 68	$1\frac{5}{8}$	
	Over 68 to 74	$1\frac{11}{16}$	
	Over 74	$1\frac{3}{4}$	
Over 40,000 to 45,000 pounds...	44 and under	$1\frac{7}{16}$	$1\frac{5}{16}$
	Over 44 to 50	$1\frac{1}{2}$	$1\frac{3}{8}$
	Over 50 to 56	$1\frac{9}{16}$	$1\frac{7}{16}$
	Over 56 to 62	$1\frac{5}{8}$	$1\frac{1}{2}$
	Over 62 to 68	$1\frac{11}{16}$	
	Over 68 to 74	$1\frac{3}{4}$	
	Over 74	$1\frac{13}{16}$	
Over 45,000 to 50,000 pounds...	44 and under	$1\frac{1}{2}$	$1\frac{3}{8}$
	Over 44 to 50	$1\frac{9}{16}$	$1\frac{7}{16}$
	Over 50 to 56	$1\frac{5}{8}$	$1\frac{1}{2}$
	Over 56 to 62	$1\frac{11}{16}$	$1\frac{9}{16}$
	Over 62 to 68	$1\frac{3}{4}$	
	Over 68 to 74	$1\frac{13}{16}$	
	Over 74	$1\frac{7}{8}$	
Over 50,000 to 55,000 pounds...	44 and under	$1\frac{9}{16}$	$1\frac{7}{16}$
	Over 44 to 50	$1\frac{5}{8}$	$1\frac{1}{2}$
	Over 50 to 56	$1\frac{11}{16}$	$1\frac{9}{16}$
	Over 56 to 62	$1\frac{3}{4}$	$1\frac{5}{8}$
	Over 62 to 68	$7\frac{13}{16}$	
	Over 68 to 74	$1\frac{7}{8}$	
	Over 74	$1\frac{15}{16}$	
Over 55,000 pounds............	44 and under	$1\frac{5}{8}$	$1\frac{1}{2}$
	Over 44 to 50	$1\frac{11}{16}$	$1\frac{9}{16}$
	Over 50 to 56	$1\frac{3}{4}$	$1\frac{5}{8}$
	Over 56 to 62	$1\frac{13}{16}$	$1\frac{11}{16}$
	Over 62 to 68	$1\frac{7}{8}$	
	Over 68 to 74	$1\frac{15}{16}$	
	Over 74	2	

Interstate Commerce Commission.

SHRINKAGE OF TIRES

TABLE 4.—DRIVING-WHEEL TIRES

Specification Class	Flange Tires		Bald Tires		Diameter of Tires, in Inches			Diameter of Wheel Center, in Inches	Shrinkage Allowance, in Inches	Length of Shims	
	No.	Width, in Inches	No.	Width, in Inches	Outside Rough	Inside Rough	Inside Finished			Short Ft. In.	Full Ft. In.
A	8 per cab	5½	..	..	62	55 13/16	55.935	56	0 065	3 8	14 7⅞
A	8 per cab	5½	..	..	62	55 13/16	55.935	56	0.065	3 8	14 7⅞
A	6	5½	..	..	68	61 13/16	61.925	62	0.075	4 0⅝	16 2¾
A	6	5½	..	..	70	61 13/16	61.925	62	0.075	4 0⅝	16 2¾
A	4	5½	2	7	80	71¾	71.909	72	0.091	4 8½	18 10 3/16
A	4	5½	4	7⅛	50	43 13/16	43.952	44	0.048	2 10½	11 6 3/16
A	8 12	5½	..	..	70	61 13/16	61.925	62	0.075	4 0⅝	16 2¾
A A	8 16	5½	..	..	64	55 13/16	55.935	56	0.065	3 8	14 7⅞
A	6	5½	2	7⅛	56	49 13/16	49.944	50	0.056	3 3¼	13 1 1/16
A	4 6	5½	2	7⅛	62	55 13/16	55.935	56	0.065	3 8	14 7⅞
A	6	5½	2	7⅛	56	49 13/16	49.944	50	0.056	3 3¼	13 1 1/16
A	16	5½	..	..	58	49 13/16	49.944	50	0.056	3 3¼	13 1 1/16
A	12	5½	..	..	57	49 13/16	49.944	50	0.056	3 3¼	13 1 1/16
A	16	5½	..	..	57	49 13/16	49.944	50	0.056	3 3¼	13 1 1/16

NOTE.—Tolerance of ±0.005 inch to be allowed for the finished inside diameter of tires.
Shrinkage allowance to be made to agree with the tabulated values as nearly as shims will permit.

TABLE 5.—TRAILING-WHEEL TIRES

Flange Tires, in Inches		Diameter of Tires, in Inches			Diameter of Wheel Center, in Inches	Shrinkage Allowance, in Inches	Length of Shims	
No.	Width	Outside Rough	Inside Rough	Inside Finished			Short, in Inches	Full, Ft. In.
4 per cab	5 1/2	31	24 13/16	24 974	25	0 026	19 5/8	6 6 1/2
4 per cab	5 1/2	34	27 13/16	27.971	28	0 029	22	7 3 15/16
2	5 1/2	42	35 13/16	35 962	36	0.038	28 1/4	9 5 1/16
2	5 1/2	56	49 13/16	49 944	50	0 056	33 1/4	13 1 1/16
2 4	5 1/2	42	35 13/16	35.962	36	0 038	28 1/4	9 5 1/16
2	5 1/2	43	35 13/16	35.962	36	0.038	28 1/4	9 5 1/16
2	5 1/2	31 1/4	24 1/16	24.225	24 1/4	0.02525	19 1/16	6 4 1/8
2	5 1/2	44	37 9/16	37.960	38	0.040	29 7/8	9 11 3/8

TABLE 6.—TRUCK-WHEEL TIRES

Flange Tires, in Inches		Diameter of Tires, in Inches			Diam. of Wheel Center, in Inches	Shrinkage Allowance, in Inches	Length of Shims	
No.	Width	Outside Rough	Inside Rough	Inside Finished			Short, in Inches	Full, Ft. In.
4	5 1/2	34	27 13/16	27.971	28	.029	22	7 3 15/16
4 2	5 1/2	36	27 13/16	27.971	28	.029	22	7 3 15/16
2	5 1/2	31	24 13/16	24.974	25	.026	19 5/8	6 6 1/2
4	5 1/2	34	27 13/16	27.971	28	.029	22	7 3 15/16
4	5 1/2	28	21 13/16	21.977	22	.023	17 1/2	5 9 1/16
4	5 1/2	31	24 13/16	24 974	25	.026	19 5/8	6 6 1/2
2	5 1/2	31 1/4	24 1/16	24.225	24 1/4	.02525	19 1/16	6 4 1/8
2	5 1/2	31 1/4	24 1/16	24 225	24 1/4	.02525	19 1/16	6 4 1/8
2	5 1/2	31 1/4	24 1/16	24 225	24 1/4	.02525	19 1/16	6 4 1/8

Heating Tires for Shrinking on Wheel Centers

Tires, when heated for application to or removal from wheel centers, should be heated slowly and uniformly around their entire circumference, and the heat applied indirectly so as to avoid the impingement of flames against the surface of the tires. A temperature of 500 to 600°F. is sufficient for tires of any size, and in no case should tires be heated hotter than 800°F., which is somewhat below the lowest visible red heat. Before placing tires on wheel centers, the bore must be clean and free from soot, rust, fins, and other obstructions

When in place on the wheel centers, tires should be clamped accurately in position and allowed to cool slowly. Rapid cooling by the application of water or a blast of air should not be permitted, and the use of steel sledges, flatters, rams, etc., for forcing tires into position should not be permitted. If it is necessary to drive a tire over a wheel center, a soft copper hammer or sledge should be used.

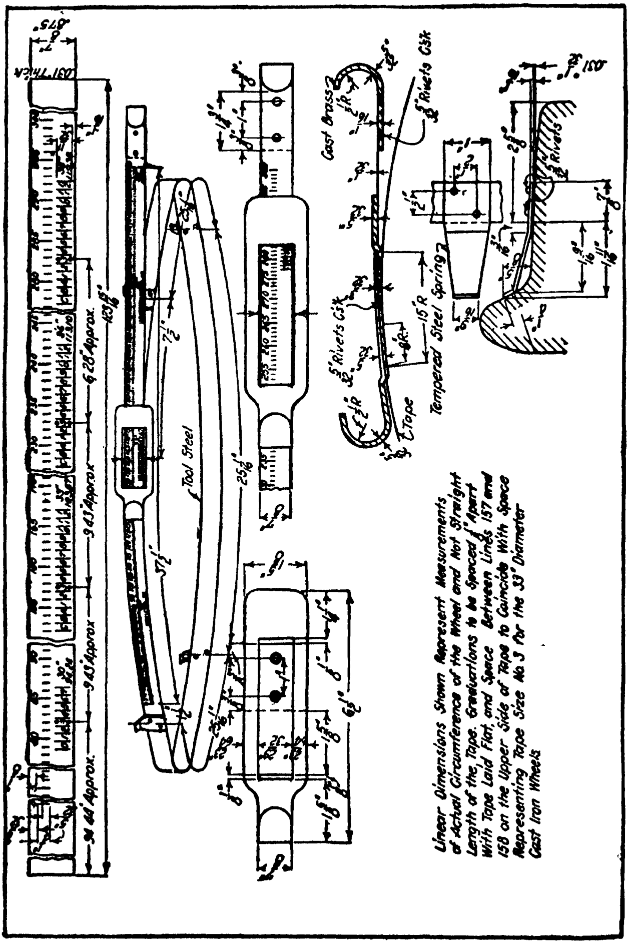

Linear Dimensions Shown Represent Measurements of Actual Circumference of the Wheel and Not Straight Length of the Tape. Graduations to be Spaced 1/8" Apart With Tape Laid Flat, and Space Between Lines 157 and 158 on the Upper Side of Tape to Coincide With Space No 3 for the 33" Diameter Representing Tape Size Cast Iron Wheels
Cast Brass
Rivets Csk
Tempered Steel Spring
Tape
Tool Steel
6.28" Approx.
9.43" Approx.
9.43" Approx.
31.44" Approx.
Rivets

FIG. 9.—Wheel-Measuring Tape and Its Use

It is considered good practice to true up the treads of locomotive driving-wheel tires after they have been applied to wheel centers, the work to be done by taking a light cut off the tire in a wheel lathe. This insures that the treads of all of the tires will be perfectly round and concentric with the journals. It also eliminates variations in diameter of tread between wheels of the same set.

Marking tires by center punch and chisel marks should not be permitted.

TABLE 7.—PRESSURE FOR FORCING PISTON RODS INTO PISTON HEADS

Diameter of Rod in Inches	Pressure in Tons	Diam. of Rod in Inches	Pressure in Tons	Diameter of Rod in Inches	Pressure in Tons
2½	30–40	3¼	40–50	4¼	55–65
2¾	30–40	3½	45–55	4½	55–65
3	35–45	3¾	45–55	4¾	60–70
		4	50–60	5	65–75

Pressures must be obtained before the collar reaches its seat, and the collar must in all cases seat solidly on piston head. The taper is 1 inch in 20 inches. American Locomotive Company.

Standard American Railway Association Wheel-Circumference Measure for Cast-Iron Cast-Steel, Wrought-Steel, and Steel-Tired Wheels

ADOPTED, 1893; MODIFIED, 1919

Instructions for Using Standard Wheel Circumference Measure for Steel, Steel-Tired, and Cast-Iron Wheels

Place tape about circumference of wheel, having the brackets in contact with flange. The normal circumference of wheels of each of the different diameters is indicated by the space marked 3. Steel and steel-tired wheels should be rejected if the scribed lines on the head piece fall to the left of the space marked C or to the right of the space marked ½. Cast-iron wheels should be rejected if the scribed line on the headpiece falls to the left of the space marked 1 or to the right of the space marked 5.

The continuous markings on the upper side of the tape may be used for mating worn wheels.

The tape and method of using are shown in Fig. 9.

PRESS-FIT PRACTICES

The two general methods of specifying the fit are by maximum pressure necessary to force the parts together, and by the difference in diameter between the mating parts. Railroads usually give maximum pressure as 6 to 10 tons per inch of diameter for cast-iron wheels and 10 to 16 tons for steel wheels. The standard lubricant for press fits is 12 pounds of white lead to 1 gallon of boiled linseed oil between the fitted parts.

Lubricant used in mounting directly affects the pressure required. Good engine oil and white lead mixed to the consistency of heavy paint is used by some of the best shops.

An objection to the maximum-pressure method is the practice of changing the lubricant if the mounting pressure is too low. The objection to the measurement method is the possibility of errors in measurement, the axle or bore of the wheel not being round—one or both being taper, and the condition of the mating surfaces. These are affected, according to Horger and Nelson of the Timken Roller Bearing Company, by the methods of machining, the number of times the parts have been forced together, the materials and heat-treatment, length of time after assembly is made and the speed with which the fit is made.

Although there is a trend toward the use of micrometers for measuring the bores for axle and crankpins, the caliper swing, or drag method, is still used in many shops with very accurate results. This method is shown on page 723. One progressive railroad forces a hardened steel hob or plug through the bore both for sizing the hole and smoothing its surface. The axle is then ground to micrometer measurements, which secures excellent results. Tests have shown that the axle is weakened greatly by the wheel mounting, and this is now partly restored by rolling the axle under very great pressure (25,000 pounds per square inch). Since rolling does not leave a perfectly round pin or axle, a light grinding cut trues it up before mounting the wheel or pin.

Some roads turn the axles and pins slightly taper on the fit. This taper varies from 0.003 to 0.005 inch in the length of the fit. One road turns the axle straight but makes the last 1½ inch of the fit 0.005 inch larger than the rest.

Experience in wheel fits would indicate that, where wheel-center hubs are very heavy, smaller allowance in the fit and lower pressures are required, because the metal in the bore resists and grips harder in the fit.

Pressures for Mounting Axles and Crankpins

TABLE 8.—MINIMUM AND MAXIMUM PRESSURES
(In Tons)

Driving Axles

Diameter Wheel Fit, in Inches	Wheel Centers			
	Cast Iron	Variation	Steel	Variation
4½	40 to 49	9	64 to 79	15
5	45 to 55	10	72 to 88	16
5½	49 to 60	11	79 to 96	17
6	54 to 66	12	86 to 105	19
6½	58 to 71	13	93 to 114	21
7	63 to 77	14	104 to 133	29
7½	67 to 82	15	112 to 143	31
8	72 to 88	16	119 to 153	34
8½	76 to 93	17	127 to 162	35
9	81 to 99	18	135 to 172	37
9½	85 to 104	19	142 to 181	39
10	90 to 110	20	150 to 191	41
10½	94 to 115	21	157 to 200	43
11	99 to 121	22	165 to 210	45
11½	103 to 126	23	173 to 220	47
12	108 to 133	25	180 to 229	49
12½	112 to 138	26	188 to 239	51
13	116 to 143	27	195 to 248	53
13½	121 to 150	29	203 to 258	55
14	125 to 155	30	210 to 267	57

Crankpins

Diameter Wheel Fit, in Inches	Wheel Centers			
	Cast Iron	Variation	Steel	Variation
3	13 to 16	3	21 to 26	5
3½	18 to 22	4	28 to 35	7
4	22 to 27	5	36 to 44	8
4½	27 to 33	6	43 to 52	9
5	31 to 38	7	50 to 61	11
5½	36 to 44	8	57 to 70	13
6	40 to 49	9	64 to 79	15
6½	45 to 55	10	72 to 88	16
7	49 to 60	11	79 to 96	17
7½	54 to 66	12	86 to 105	19
8	58 to 71	13	93 to 114	21
8½	63 to 77	14	100 to 123	23
9	67 to 82	15	108 to 132	24
9½	71 to 88	17	115 to 141	26
10	76 to 94	18	122 to 150	28
10½	81 to 100	19	129 to 159	30
11	85 to 105	20	136 to 168	32

TABLE 8.—MINIMUM AND MAXIMUM PRESSURES—*Continued*

Locomotive Truck Axles

Diameter Wheel Fit, in Inches	Wheel Centers			
	Cast Iron	Variation	Steel	Variation
3½	18 to 22	4	27 to 33	6
4	22 to 27	5	33 to 40	7
4½	27 to 33	6	40 to 49	9
5	31 to 38	7	46 to 57	11
5½	36 to 44	8	54 to 66	12
6	40 to 49	9	60 to 73	13
6½	45 to 55	10	67 to 82	15
7	49 to 60	11	73 to 90	17
7½	54 to 66	12	81 to 99	18
8	58 to 71	13	88 to 107	19
8½	63 to 77	14	95 to 116	21
9	67 to 82	15	101 to 124	23
9½	72 to 88	16	108 to 132	24
10	76 to 93	17	115 to 141	26
10½	81 to 100	19	122 to 150	28

Car or Tender Axles

Size of Journal	Diameter Wheel Fit, in Inches	Wheel Centers			
		Cast Iron	Variation	Steel	Variation
4 × 8	5¾	35 to 60	25	55 to 80	25
4½ × 8	5¾	35 to 60	25	55 to 80	25
5 × 9	6½	40 to 65	25	70 to 100	30
5½ × 9	6½	40 to 65	25	70 to 100	30
5½ × 10	7	45 to 70	25	75 to 110	35
6 × 10	7⅝	50 to 75	25	80 to 120	40
6 × 11	7⅝	50 to 75	25	80 to 120	40
6½ × 11	7 13/16	52 to 77	25	80 to 120	40
6½ × 12	8⅛	54 to 79	25	85 to 130	45

Crankpin Turning

A shop putting in crankpins under heavy pressures states that they turn the pins 0.003 inch taper on the fit and make the pin 0.022 inch oversize at the small end and 0.025 oversize at large end. This table shows actual pressures required with pins of diameter given.

Diameter Pin, Inches	Pressure, Tons	Diameter Pin, Inches	Pressure, Tons
$6\frac{3}{4}$	95	$6\frac{11}{16}$	90
$6\frac{13}{32}$	90	$6\frac{1}{8}$	90
$6\frac{11}{16}$	95	$6\frac{13}{32}$	90
$6\frac{3}{8}$	90		

TAPER FITS USED IN LOCOMOTIVE WORK

There are several different tapers used in locomotive work, the tapers varying from $\frac{1}{16}$ to $1\frac{1}{2}$ inches to the foot. The Santa Fé system has adopted the following standards:

Taper of $\frac{1}{16}$ inch in 12 inches for:
- Bolts for main and side rods.
- Bolts for engine frames.
- Eccentric splice bolts.
- Eccentric crank bolts.
- Long reverse-yoke pin in Baker valve gear.

Taper of $\frac{3}{8}$ inch in 12 inches for:
- Bell-crankpin.
- Combination-lever pin—long.
- Link-block pin.
- Reverse-shaft hanger pins, Stephenson gear.
- Rocker-arm pins in single shear.
- Valve-stem sockets.

Taper of $\frac{1}{2}$ inch in 10 inches for:
- Combination-lever pin—short.
- Connecting-rod pin—in crosshead
- Connecting-rod pin bushing—in crosshead
- Eccentric-rod pins.
- Piston-rod fit in crosshead.
- Piston-rod fit in spider.
- Reach-rod pins.
- Reverse-shaft hanger pins—Walschaert gear.
- Reverse-yoke pin—short—Baker gear.
- Reverse-gear piston fit in spider and in crosshead.
- Radius-bar pin.
- Rocker-arm pins in double shear.
- Union link pins.

Valve-rod knuckle joint pins.

Valve-rod pins.

Valve-stem crosshead pin.

A taper of ¾ inch in 12 inches is used for the eccentric-blade pins and of ¾ inch in 10 inches for the center connecting-rod pin.

Crosshead and wrist pins, ¾ inch in 12 inches.

Side-rod knuckle pins, 1½ inches in 12 inches.

Driving-box wedges 1 inch in 12 inches. Driving-box flanges, ⅛ inch in 7 inches, but for roller bearings, ⅜ inch in 12 inches.

A taper of 1½ inch in 12 inches is used for crown-bar bolts where they fit in the crown sheet. The same taper is used for side-rod knuckle-joint pins.

Taper Threads in Locomotive Work

Nearly all taper threads used in railway work are of the standard pipe-thread taper of ¾ inch in 12 inches or 1 inch in 16 inches. The diameters, however, do not conform to standard pipe sizes and 12 threads to the inch is usual, regardless of diameter. On the Santa Fé system, threads of 6, 9, 10, and 11 per inch are used in some cases.

MACHINING ROD ENDS

Milling is replacing slotting for machining rod ends. In solid-end rods, the block is removed either with the oxyacetylene torch or by drilling a hole large enough for a helical milling cutter to go through. In some cases a hole is drilled for starting the torch cut but is not necessary as a hole can be burned through a 4-inch piece in less than 30 seconds. Milling out the block from the solid can be done at from ⅜ to ⅞ inch per minute depending on the diameter of the cutter and the thickness of the rod. The ⅜-inch feed is for a rod 7 inches thick. For finishing, the cut, whether the block is milled out or burned out, usually varies from 3 to 5½ inches per minute.

WEAR ALLOWANCES, TOLERANCES, AND FITS

The following pages give the wear allowances, tolerances, and fits in use on one of the large lines. The data are concise and easily understood.

CROWN-BRASS PRACTICE

Crown-brass practice varies on different railroads. These tables show the general dimensions, including relief, used by a large railroad and representing modern practice.

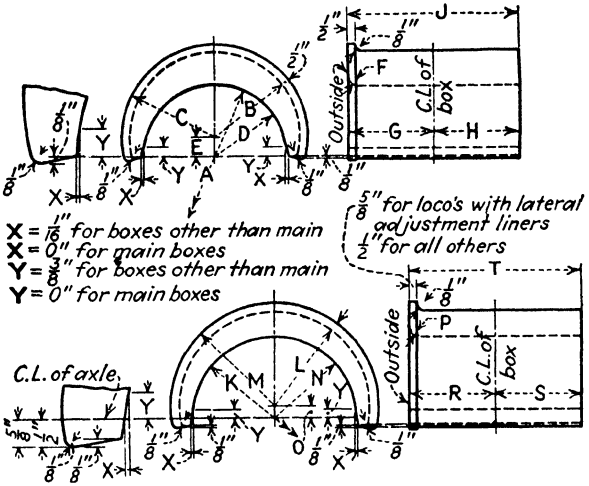


Table 9.—Details of Crown Brasses with Tables Showing Relief and Dimensions of Various Types
(Int. is intermediate)

Where Used	No.	Dia. Axle *A* in In.	*B* in In.	*C* in In.	*D* in In.	*E* in In.	*F* in In.	*G* in In.	*H* in In.	*J* in In.
Front and back	4	8½	5¼	5¾	4¼	1⅜	..	5 3/16	5 3/16	10⅜
Main	2	9	5½	6	4½	1⅜	5/16	5 3/16	5 3/16	10⅜
Front back main	6	10½	6¼	6¾	5¼	1	5/16	5⅞	6⅛	12
Front int. and back	6	8½	5¼	5¾	4¼	1⅜	..	5 3/16	5 3/16	10⅜
Front int. back	6	7¼	4½	5	3⅝	1	..	3 15/16	3 15/16	7⅞
Main	2	7½	4½	5	3¾	1	..	3 15/16	3 15/16	7⅞
Front	2	8½	5¼	5¾	4¼	1⅜	..	5 3/16	5 3/16	10⅜
Front int. back	6	8½	5¼	5¾	4¼	1⅜	..	5 3/16	5 3/16	10⅜
Main	2	9	5½	6	4½	1⅜	5/16	5 3/16	5 3/16	10⅜
Front int. main back	8	7½	4½	5	3¾	1	..	3 15/16	3 15/16	7⅞
Front back	4	8	5	5½	4	1⅜	..	4 15/16	5 7/16	10⅜
Main	2	8½	5	5½	4¼	1⅜	..	4 15/16	5 7/16	10⅜
All driving boxes	4 per truck	10	6	6½	5	¾	..	5 123/128	5 123/128	11 63/64
All driving boxes	8 per cab	12½	7⅜	7⅞	6¼	⅞	..	6 7/16	6 9/16	13

TABLE 9.—DETAILS OF CROWN BRASSES WITH TABLES SHOWING RELIEF AND DIMENSIONS OF VARIOUS TYPES—*Continued*

Where Used	No.	Dia. Axle *K* in In.	*L* in In.	*M* in In.	*N* in In.	*O* in In.	*P* in In.	*R* in In.	*S* in In.	*T* in In.
Front, main and back	6	10½	6¼	6¾	5¼	1	5/16	7 7/16	7 9/16	15
Front, back and int.	6	11	6⅝	7⅛	5½	7/8	5/16	6⅞ F.&B. 6¾ int.	7⅛ F.&B. 7¼ int.	14
Main	2	12	7⅛	7⅝	6	7/8	5/16	6¾	7¼	14
Front, back and int.	6	11	6⅝	7⅛	5½	7/8	..	5⅞	7⅛	13
Main	2	12	7⅛	7⅝	6	1⅛	5/16	5⅞	7⅛	13
Front, back and int.	6	10½	6¼	6¾	5¼	1	5/16	5⅞	6⅛	12
Main	2	11	6¼	6¾	5½	1¼	5/16	5⅞	6⅛	12
Front back int. (H.P. & L.P.)	12	9½	5¾	6¼	4¾	1⅜	0 int. 5/16 F.B.	5⅞	6⅛	12
Main (H.P. & L.P.)	4	10	6	6½	5	1⅜	5/16	5⅞	6⅛	12
Main	2	12¾	7½	8	6⅜	1⅛	..	5⅞	7⅛	13
Front, back int. main (H.P. & L.P.)	16	11	6⅝	7⅛	5½	7/8	5/16	5⅞	6⅛	12
Front, back int. main (H.P. & L.P.)	16	11	6⅝	7⅛	5½	7/8	5/16 main F.B. = 0 int.	5⅞	7⅛	13
Front, back and int. (H.P. & L.P.)	12	11	6⅝	7⅛	5½	7/8	..	5⅞	7⅛	13
Front, back int. style No. 1 (H.P. & L.P.)	12	11	6⅝	7⅛	5½	7/8	..	6⅞	6¾	13⅝
Front, int. main (H.P. & L.P.)	12	10	6	6½	5	1⅜	5/16	5⅞	6⅛	12
Main (L.P.)	2	11½	6⅞	7⅜	5¾	7/8	5/16	6	7⅛	13⅛
Main (L.P.)	2	11½	7 5/16	7 3/16	5¾	1⅛	5/16	6	7⅛	13⅛

TABLE 10.—REBUILDING HUB-LINER OF LOCOMOTIVE DRIVING WHEELS BY WELDING

This is recent practice of a large railroad shop as reported by Irving T. Bennett of Revere Brass and Copper Co.

Process	Rod Diameter	Amperes	Volts	Rod Used per Hour in Pounds	
				Used	Deposited
Metal arc	3/8	380	30	28.49	27.79
		450	30	35.76	34.17
		500	30	38.72	36.72
	1/2	500	30	43.10	41.30
		600	30	46.69	44.39
		700	33	54.99	50.57
	5/8	700	33	62.46	57.78
		800	35	66.00	57.60
Carbon arc	1/2	500	42	47.96	47.96*
		500	42	97.68	97.46†
	5/8	700	45	150.47	56.03†

Boxes inclined 10 degrees to permit "up-hill" welding, which is essential.
* Metal fused to base to insure good bond.
† Metal simply melted down in carbon flame and puddled.

Fits Used in Locomotive Repair Work

The Heald Machine Company gives the following suggestions for running fits in railway shop work, based on observations in many localities:

Valve-motion pins or bolts and bushings, 0.003 to 0.006 inch.

Side-rod knuckle pins and bushings, 0.005 to 0.008 inch.

Crankpins and rod bushings 6 inches or less in diameter, 0.010 to 0.015 inch.

Crankpins and rod bushings over 6 inches in diameter, 0.015 to 0.020 inch.

Driver axles and driver boxes, 0.015 to 0.025 inch.

Piston rod and metallic packing, 0.001 to 0.0015 inch per inch of diameter.

Piston-rod allowable variation in diameter from end to end, 0.002 inch.

Air-pump piston rods, allowable variation in diameter from end to end, 0.001 inch.

One method of repairing motion work is to true up the hole in the lever and then grind the outside of the bushing 0.004 inch larger than the hole. The hole in the bushing is ground 0.008 inch larger than the pin. Forcing the bushing in the lever reduces the hole to about 0.004 inch for an oil film.

Brass cylinder bushings in triple valves require careful attention. When the difference in diameter between the two ends exceeds 0.002 inch, the bushing should be reground just enough to remove the worn spots.

STANDARD ALLOWANCES FOR DIFFERENT KINDS OF FITS

In all work requiring a fit, either force, driving, push, or running, the diameter of the hole shall conform to the dimension given on the tracing within the limits herein given, while the diameter of the bolt, pin, or shaft which goes into the hole shall be of such dimensions that it will fit in the hole as here indicated for the different classes of work.

Where allowances for fits are given on tracings or in other maintenance instructions, the allowances there specified shall govern the allowances for those fits only.

The allowances for different fits and for tolerances of holes as given in the following table shall be used, unless otherwise specified on tracings or in other maintenance instructions. This table gives allowances covering average conditions.

Nominal Diameter, in Inches	Limits	Tolerances for Standard Holes	Allowances for Different Kinds of Fits			
			Running Fit	Push Fit	Driving Fit	Force Fit
Up to ½	High	+0.0005	−0.0010	−0.0003	+0.0005	+0.0010
	Low	−0.0005	−0.0020	−0.0008	+0.0003	+0.0005
½ to 1	High	+0.0010	−0.0015	−0.0003	+0.0010	+0.0020
	Low	−0.0005	−0.0030	−0.0008	+0.0008	+0.0015
1 to 2	High	+0.0010	−0.0020	−0.0003	+0.0015	+0.0040
	Low	−0.0005	−0.0040	−0.0008	+0.0010	+0.0030
2 to 3	High	+0.0015	−0.0025	−0.0005	+0.0025	+0.0060
	Low	−0.0010	−0.0045	−0.0010	+0.0015	+0.0045
3 to 4	High	+0.0015	−0.0030	−0.0005	+0.0030	+0.0080
	Low	−0.0010	−0.0050	−0.0010	+0.0020	+0.0060
4 to 5	High	+0.0020	−0.0035	−0.0005	+0.0035	+0.0100
	Low	−0.0010	−0.0060	−0.0010	+0.0025	+0.0080
5 to 6	High	+0.0020	−0.0040	−0.0005	+0.0040	+0.0120
	Low	−0.0010	−0.0070	−0.0010	+0.0030	+0.0100
6 to 8	High	+0.0020	−0.0045	−0.0005	+0.0045	+0.0140
	Low	−0.0010	−0.0080	−0.0015	+0.0035	+0.0120

For all work in which a force, driving, push, or running fit is not required, the size of bolt or shaft shall control and the diameter shall be an even dimension within certain limits, governed by shop practice.

For machine-turned bolts in drilled holes, the hole shall be $\frac{1}{64}$ inch larger than the nominal size of the bolt.

For rough-turned bolts in drilled holes, the hole shall be $\frac{1}{32}$ inch larger than the nominal size of the bolt.

Cored holes shall be $\frac{1}{16}$ inch larger than the nominal size of the bolt.

Punched holes shall be either $\frac{1}{32}$ or $\frac{1}{16}$ inch larger than the bolt or rivet, according to whether it is a small or large hole and based on the thickness of the material.

WEAR ALLOWANCES FOR GENERAL MOTORS SERIES 71 DIESEL ENGINES—*Locomotive*, November, 1944

Piston: Ring Fits, Compression Ring, and Groove Width

Top ring: minimum: 0.010 inch. At 0.022 inch clearance replace the piston and use new rings.

Second ring: minimum 0.008 inch. At 0.015 inch replace the piston.

Third and fourth ring: minimum 0.006 inch. At 0.013 inch replace the piston.

Oil ring to groove: minimum 0.0015 inch. At 0.008 inch replace the piston.

PISTON AND CYLINDER LINER

Insert 0.005-inch feeler ribbon ½ inch wide full length of liner. Insert bare piston (no pin or rings) upside down. When the piston is released, it should slip through the liner. Repeat with ribbon moved 90 deg. in liner. Worn diameter at top of ring travel should not exceed unworn diameter by more than 0.008 inch. Piston-to-liner minimum clearance should be 0.006 inch.

Piston and Piston Pin

Minimum clearance is 0.0025 inch radial. Replace at 0.010 inch.

Gap in Piston Ring—Ring Closed in Liner

Compression rings: minimum 0.020 to 0.025 inch. Oil control rings: minimum 0.010 to 0.020 inch. Replace all rings at overhaul.

Crankshaft

End bearings and crank pins: replace or regrind when taper and out of round exceed 0.003 inch.

Main center bearing: minimum clearance 0.002 inch. Replace at 0.006 or when the shell thickness is less than 0.153 inch, at the center.

Thrust bearing-end play: minimum 0.004 inch. Replace thrust washer at 0.018 inch.

Connecting rod journal and shell: minimum 0.002 inch. Replace at 0.006 inch or when shell thickness is less than 0.153 inch at the center. Connecting rod bushing at piston pin: minimum 0.0015 inch radial. Replace at 0.010 inch.

Camshaft and intermediate bearing: minimum 0.0025 inch. Replace when lower shell thickness is less than 0.340 inch.

Camshaft or balance shaft and bearing: radial minimum 0.0015 inch. Replace at 0.006 inch. End play minimum 0.005 inch. Replace thrust washers at 0.018 inch.

Rocker arm and shaft: minimum 0.001 inch. Replace at 0.004 inch. Cam follower bushing and pin-replace at 0.005 in. radial.

Valve and valve guide: minimum 0.001 inch. Replace at 0.006 inch.

Cylinder head inserts: press fit for seats, 0.0005 to 0.0025 inch. Seat width $\frac{3}{64}$ inch; not over $\frac{5}{64}$ inch. Eccentricity of seat not to exceed 0.001 inch by dial indicator.

The following are suggestions for the mechanic in overhauling engines of this type:

The replacement of a part becomes worth while only when wear or damage threaten to limit life or performance of the engine.

In estimating the prospective life of worn parts, the condition of friction surfaces tells as much as the actual measured wear. This requires the judgment of a skilled mechanic.

Minimum tolerance is the smallest clearance between parts which will permit satisfactory lubrication.

"*Replace at*" *tolerance* is the maximum clearance which may be considered safe until the next regular overhaul.

TOLERANCES AND WEAR LIMITS FOR DIESEL ENGINES

The diesel engines built by the Electro-Motive Division of the General Motors Corporation for use on diesel-electric locomotives are permitted the following tolerances and wear limits. The tolerances on new engines are given in the first column and the waer limit in the right-hand column.

	New	Wear Limit
Cylinder to piston	0.0095 to 0.0135	0.020
Piston pin: Pin to floating bushing	0.003 to 0.005	0.010
Pin to piston bushing	0.003 to 0.0045	0.010
Rod to floating bushing	0.0045 to 0.0065	0.012
Piston rings: Compression ring in groove	0.004 to 0.008	0.010
Compression ring gap	0.035 to 0.045	0.070
Oil ring in groove	0.002 to 0.006	0.010
Oil ring gap	0.035 to 0.045	0.070
Main bearing to crankshaft journal	0.007 to 0.010	0.020
Crankshaft end thrust	0.010 to 0.015	0.030
Connecting rod bearing	0.008 to 0.010	0.015
Exhaust valve stem to guide	0.0045 to 0.006	0.010
Exhaust valve rocker arm bushing	0.002 to 0.004	0.008
Oil pumps: Drive shaft to bushing	0.0015 to 0.0035	0.007
Idler gear to shaft	0.0015 to 0.0035	0.007
Backlash in pump gears	0.010 to 0.014	0.030
Gear end clearance	0.007 to 0.010	0.020
Camshaft and gear train: Crankshaft bearings	0.002 to 0.005	0.010
Gear backlash	0.008 to 0.012	0.030
Supercharger blower: Clearance, rotor to end plates	0.012 to 0.023	
Clearance, housing to rotor	0.008 to 0.012	
Clearance, rotor to rotor	0.008 to 0.012	
Radial clearance, rotor shaft bearing	0.003 to 0.0045	0.008
Thrust clearance, rotor shaft bearing	0.002 to 0.005	0.010
Backlash, synchronizing gears	0.000 to 0.0015	0.006

TABLE 11.—LIMITS OF WEAR FOR LOCOMOTIVES IN SHOP FOR CLASS 4, OR HEAVIER, REPAIRS

ITEM	INSTRUCTIONS
Air pumps	Regrind air cylinder: When 0.012 inch out of round When 0.012 inch tapered Regrind steam cylinder: When 0.012 inch out of round When 0.012 inch tapered
Connecting-rod bushings	Renew when 3/64 inch oversize
Connecting-rod eyes	Regrind when 1/64 inch out of round (for new bushings)
Crosshead	Reline when lateral play exceeds 1/8 inch
Crankpins, main, *21a*, *21b*, 22	Return: when 1/64 inch out of round when 1/64 inch tapered Renew when 1/2 inch undersize
Crankpins, main, other than *21a*, *21b*, 22	Return: when 1/64 inch out of round when 1/64 inch tapered Renew when 3/8 inch undersize
Crankpins, all others	Return: when 1/32 inch out of round when 1/32 inch tapered Renew when 3/8 inch undersize
Cylinders	Rebore: when 3/32 inch out of round when 3/32 inch tapered
Cylinder bushings	Rebore: when 3/32 inch out of round when 3/32 inch tapered Renew when 1/2 inch oversize
Driving boxes	Remachine when 1/32 inch tapered
Driving-box crown brasses	Renew when less than 1 1/4 inches in thickness
Eccentrics	Return when 3/32 inch out of round Renew when 1/4 inch undersize
Eccentric straps	Rebore when 1/16 inch out of round Renew when 3/32 inch oversize (3/16 inch side play)
Journals, main	Return: when 1/32 inch out of round when 1/32 inch tapered Renew when 1/2 inch undersize
Journals, other than main	Return: when 1/32 inch out of round when 1/32 inch tapered Renew when 1/2 to 3/4 inch undersize (according to class) see C-29237
Piston-bull rings	Renew when 3/16 inch undersize to 29 inches diameter; 1/4 inch, over 29 inches
Piston rods	Regrind: when 0.010 inch out of round when 0.010 inch tapered Renew when 1/4 inch undersize
Rocker arm	Return when 1/32 inch out of round
Rocker-box bushings	Renew when 1/32 inch out of round
Valve-chamber bushings	Renew: when 3/64 inch out of round when 3/64 inch tapered
Valve-bull rings	Renew when 3/32 inch undersize
Valve-motion bushings	Renew when 1/32 inch oversize
Valve-motion pins	Renew when 1/32 inch undersize
Valve stems	Regrind: when 0.010 inch out of round when 0.010 inch tapered Renew when 1/4 inch undersize
Locomotive frames—shoe fits	Build up by welding when wear on sides exceeds 1/16 inch
Shoes and wedges	Discard when flanges are worn on inside more than 1/16 inch
Crosshead wrist pin	Renew when body of pin is 1/8 inch oversize

TABLE 12.—USES OF STEELS IN RAILROAD WORK
Suggested by the American Association of Railroads

Grade	Machine Rating, Per Cent	Heat-Treatment	Application, Locomotive, and Cars
1010	45	Carburize	Pins—Cold formed
1015	45	Carburize or Normalize or As Forged	Bolt heading stock
1020	50		Bolt heading stock
X1020	55		Brake pins
1035	60	Normalize	Brake-beam truss rods
1045	50	N. Q. & T.†	Small forgings
1060	40	N. Q. & T.†	Draw-bar and coupler knuckle pins
1120	100	....	Screw stock
X1315	85	Carburize	Same as X1020
X1340	60	N. Q. & T.†	Same as 1045
2110	60	None	Staybolts
2115	50	Carburize or as rolled	Motion work pins Engine bolts
2330	50*	N. Q. & T.†	Automotive bolts
3130	45*	N. Q. & T.†	High-temperature bolts
3140	40*	N. Q. & T.†	Small high-tensile forgings

* Annealed.
† Normalized, quenched, and tempered.

BRONZE BEARINGS FOR LOCOMOTIVES

ADOPTED, 1916; REVISED, 1926, 1934.—A.A.R.

Phosphor Bronze.—Shoes and wedges, floating rod bushings, or other uses where a hard-wearing surface is required.

Hard Bronze.—General-purpose wearing metal may be cast in either sand or metal molds, for rod bushings, shoes and wedges, crosshead gibs, engine truck and trailer brasses.

Medium Bronze.—May be cast in sand or metal molds for driving box, engine- and trailer-truck brasses, hub liners, and bearings requiring lining metal for facing or lining.

Soft Bronze.—Generally cast in metal molds for driving boxes and special purposes where a soft metal is desired.

Chemical Properties and Tests

Chemical Composition.—The material shall conform to the following requirements as to chemical composition:

	Phosphor Bronze	Hard Bronze	Medium Bronze	Soft Bronze
Tin	9 to 11	7 to 10	6 to 8	4 to 6
Lead	9 to 11	10 to 15	14 to 22	23 to 27
Phosphorus	0.2 to 0.4	....	....	....
Zinc, maximum	0.5	1.25	1.25	0.75
Other impurities, maximum	1.0	0.75	0.75	0.75
Copper	Balance	Balance	Balance	Balance

CARBON STEEL AXLES FOR CARS AND LOCOMOTIVE TENDERS

ADOPTED, 1914; REVISED, 1926, 1934, 1936—A.A.R.

Chemical Composition.—The steel shall conform to the following requirements as to chemical composition:

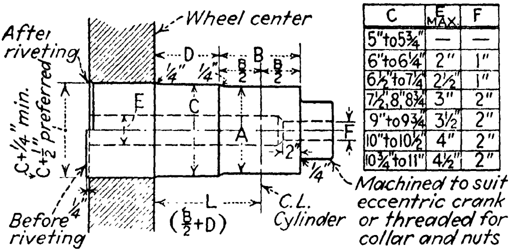
Carbon, per cent	0.40 to 0.55
Manganese, per cent	0.50 to 0.90
Phosphorus, not over, per cent	0.05
Sulphur, not over, per cent	0.05

Drop Test.—At a temperature between 40 and 120°F., axles must pass the following drop test from a "tup" of 2,240 pounds. Axle to be rotated 180 degrees after first and third blows.

TABLE 13.—DROP-TEST SPECIFICATIONS

Classification of Axles	Size of Journal, in Inches	Diameter of Axle, at Center, in Inches	Length of Axle, in Inches	Height of Drop, in Feet	Number of Blows	Maximum Permanent Set, in Inches
A	3¾ × 7	4¼ 4⅜ 4½	83¼	18 19 20	5	8¾ 8⅜ 8
B	4¼ × 8	4⅝ 4⅞ 5	84¼	22½ 23½ 25	5	7½ 7¼ 7
C	5 × 9	5⅜ 5½ 5⅝	86½	29 30 31½	5	6¼ 6 5¾
D	5½ × 10	5⅞ 6 6⅛	88½	34½ 36 37½	5	5½ 5¼ 5
E	6 × 11	6 7/16 6 9/16 6 11/16	90¾	41½ 43 44½	5	4¾ 4½ 4¼

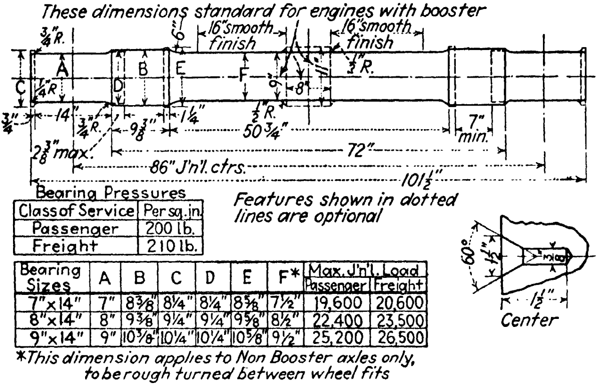
Weights.—The maximum weights of smooth-forged and rough-turned axles in any shipment shall not exceed those given in Table 14.



C	E MAX.	F
5" to 5¾"	—	—
6" to 6¼"	2"	1"
6½" to 7¼"	2½"	1"
7½", 8", 8¾"	3"	2"
9" to 9¾"	3½"	2"
10" to 10½"	4"	2"
10¾" to 11"	4½"	2"

Machined to suit eccentric crank or threaded for collar and nuts

FIG. 10.—Standard American Association of Railroads Crankpins



These dimensions standard for engines with booster

Features shown in dotted lines are optional

Bearing Pressures

Class of Service	Per sq. in.
Passenger	200 lb.
Freight	210 lb.

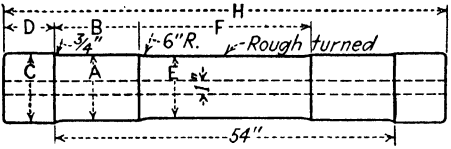
Bearing Sizes	A	B	C	D	E	F*	Max. J'n'l. Load Passenger	Max. J'n'l. Load Freight
7"×14"	7"	8⅜"	8¼"	8¼"	8⅝"	7½"	19,600	20,600
8"×14"	8"	9⅜"	9¼"	9¼"	9⅝"	8½"	22,400	23,500
9"×14"	9"	10⅜"	10¼"	10¼"	10⅝"	9½"	25,200	26,500

**This dimension applies to Non Booster axles only, to be rough turned between wheel fits*

FIG. 11.—A.A.R. Dimensions of Trailer-Truck Axles

TABLE 14.—MAXIMUM WEIGHT OF AXLES

Classification of Axles	Size of Journal in Inches	Smooth-Forged with Rough-Turned Journals and Wheel Seats	Rough Turned All Over
A	3¾ × 7	435	425
B	4¼ × 8	530	520
C	5 × 9	705	695
D	5½ × 10	835	825
E	6 × 11	1,015	1,005
F	6½ × 12	1,190	1,175

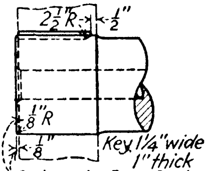


BEARING SIZES	A	B⊕	C	D⊕	E-NOT LESS THAN	F⊕	H	I*	MAX JNL. LOAD PASS	MAX JNL. LOAD FRT.& SW
7"x9"	7"	10"	7½	7"	6½"	34"	68"	-	11,000	12,600
8 x10	8	11	8½	7½	7½	32	69	-	14,000	16,000
9 x12	9	13	9½	7½	8½	28	69	-	18,900	21,600
10 x12	10	13	10½	8	9½	28	70	2	21,000	24,000
11 x13	11	14	11½	8	10½	26	70	3	25,000	28,600
12 x13	12	14	12½	8	11½	26	70	3	27,300	31,200
13 x14	13	15	13½	8	12½	24	70	4	31,800	36,400
14 x14	14	15	14½	8	13½	24	70	4	34,300	39,200

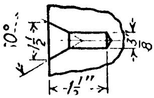
⊕ These dimensions apply to main axles Length of wheel fits and journals on axles other than main to be governed by corresponding dimensions of main axle.

Note:-If ends of axle are to project $\frac{1}{8}$" beyond faces of hubs dimension (H) will be $\frac{1}{4}$" longer than shown in table.

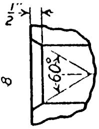
Piston rod and key taper in crosshead-A.A.R.



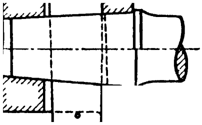
Optional:-End of axle may be flush with face of hub if desired



Center for solid axles



Center for hollow axles

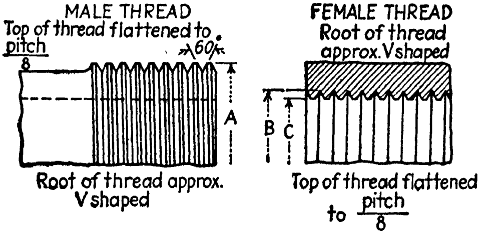


Taper {*Rod-$\frac{3}{4}$"(on diam.) in 12"* / *Key-$\frac{1}{2}$" in 12"*} *or* {*Rod-$\frac{1}{4}$"(on diam.) in 5"* / *Key-$\frac{3}{8}$" in 12"*}

FIG. 12.—A.A.R. Standard Locomotive Driving Axles and Taper of Piston Rod and Keys

THREADS FOR LOCOMOTIVE INJECTOR COUPLINGS

Note that the entire flat of ⅛ thread depth is taken from the tops of threads, leaving a V at the root.


MALE THREAD
Top of thread flattened to pitch/8
60°
A
Root of thread approx. V shaped
FEMALE THREAD
Root of thread approx. V shaped
B
C
Top of thread flattened to pitch/8

C = B − 151″
A Max. = B Min. − 0.022″ A Min. = A Max. − 0.005″
B Max. = B Min. + 0.005″

Pipe size, inches		Normal Size of Thread, Inches	Threads per Inch	O.D. of Flattened Male Thread A		O.D. of Sharp V in Female Thread, B	
Iron	Copper			Maximum, Inches	Minimum, Inches	Maximum, Inches	Minimum, Inches
1		1¾	10	1.728	1.723	1.755	1.750
1¼	1¼	2	10	1.971	1.966	1.998	1.993
1½	1½	2⅜	10	2.375	2.370	2.402	2.397
1½	1¾	2 13/16	10	2.796	2.791	2 823	2.818
2	2	3	10	3.009	3.004	3.036	3.031
2	2¼	3	10	3.009	3.004	3.036	3.031
2½	2½	3½	10	3.488	3.483	3.515	3.510
3	2¾, 3¼	4⅛	10	4.103	4.098	4.130	4.125

SECTION XXVII

SHOP TRIGONOMETRY[1]

ANGLE CONSTANTS

The laying out of angles is sometimes difficult by ordinary methods and a little knowledge of shop trigonometry is very useful. It is really a system of constants or multipliers based on the fact that there are always fixed proportions between the sides and angles of triangles and other figures. Figure 1 shows a 30-degree angle with 1-, 2-, and 3-inch arcs, 1*c*, 2*f*, and 3*i*. It will be found that every similar measurement is in exact proportion to the radius, thus 2*d* is exactly twice the length of 1*a*, and *hi* is just three times

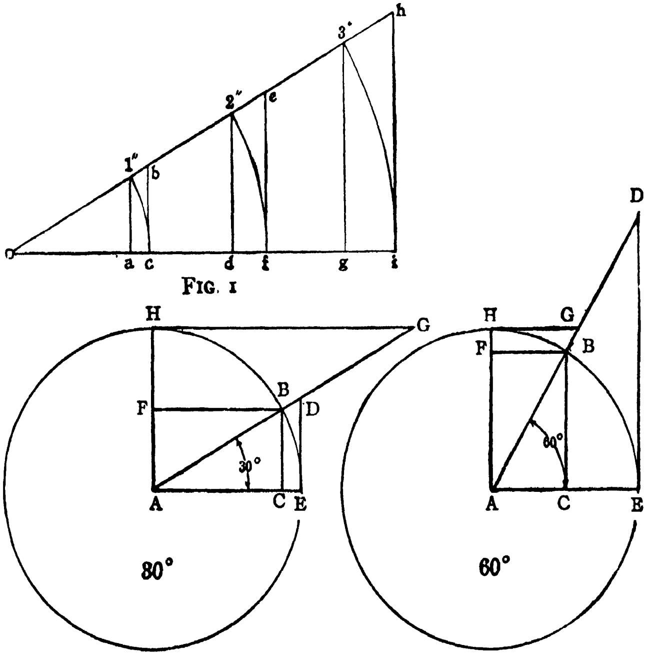


FIG. 1

FIG. 2

FIG. 3

FIGS. 1 to 3.—Diagrams Showing Angle Constants

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[1] **Note.—Reference letters on Figs. 8 to 19, p. 1199, Fig. 22, p. 1208, Figs. 24 to 32, pp. 1210 and 1211, have been changed since the 7th edition to conform with formulae on pp. 1201 to 1207.**

bc. So, if we know the distance *ac* for a 1-inch radius for any angle, a similar distance, as *gi* for the same angle, will be in exact proportion to the radius of the circle to *one*, which is the base. All these parts are named as shown in Figs. 2, 3, and 4.

The exact proportions of all the various parts have been figured for each part of a degree that is likely to be needed in ordinary work, and these figures are given in the tables which follow. These numbers are simply multipliers or constants for a radius of one, and for any other radius we multiply the numbers given by the radius we are using. These tables form the most accurate means of calculating many problems as will be shown. These constants can represent *one* of anything, inches, feet, meters, or miles, and the answer will be in the same unit. In tool work they are usually in inches, but the relation is the same regardless of the unit.

Angle Is Always Taken Each Side of the Center Line as Shown (Fig. 4)

Lines AE and AH are each called radius of the circle.
AC is called cosine of the angle.
FB is always the same as cosine of the angle.
CE is called the versed sine of the angle.
FH is called the coversed sine of the angle.
CB is called the sine of the angle.
ED is called the tangent of the angle.
HG is called the cotangent of the angle.
AD is called the secant of the angle.
AG is called the cosecant of the angle.

The names always refer to the angle on one side of the center line and not to the total or included angle. In dealing with a 60-degree thread, we divide this by a center line and call the angle 30 degrees in all our calculations. Everything is based on the radius of a circle, and a 1 radius is used as the base. Perhaps the three most important parts are the *sine*, the *tangent*, and the *secant*, these being CB, ED, and AD in all three of the figures. From this it will be seen that the sine is half the chord or the distance from the radius to the horizontal. The tangent ED is the distance from the horizontal radius to an extension of the radius at the angle given. The secant is the distance along the radius from the center to the tangent. From C to E is called the *versed sine* and is the distance from the center of the chord to the outer circle.

The angle considered in this work is always less than 90 degrees, and the angle between the angle used and 90 degrees, or the angle which is necessary to complete this to 90 degrees is called the *complementary angle.* In the first case the complementary angle is 60 degrees, in the second case 30 degrees, and in the third case 45 degrees. The *cosine* is the distance FB, the *cotangent* is HG, the *cosecant* is AG, and the *coversed sine* is FH in all three examples. In the 45-degree angle it will be seen that the various parts are alike in both angles, as the sine is the same as the cosine, while the sine of the angle of 30 degrees is the same as the cosine of the angle of 60 degrees. These facts will be borne out by the tables and can be seen by studying the diagrams or by making any calculation and then proving it as near as may be on the drawing board.

All this is interesting, but unless it is useful it has no value to the practical man, so we shall see where it can be used to advantage in saving time and labor.

Perhaps the easiest application is in finding the depth of a V thread without making any figures. The angle is 60 degrees or 30 degrees each side of the center line. The pitch is 1 inch, so that each side is also an inch; and so the radius is an inch, the depth of the thread is the distance *AC* or *FB*, and is the cosine of the angle. Looking in the table for the cosine of the angle of 30 degrees we find 0.86603, and as the radius is 1, this gives us the depth directly as 0.86603 inch. If the radius was 2 inches, we would multiply by 2, or if it was ½ inch, divide by 2 and get the exact depth with almost no figuring. Suppose, on the other hand, that the thread was 1 inch deep and we want to find the length of one side, the angle remaining the same as before. In this case we have the depth which is the line *AE*, and we wish to find *AD* which is the secant, so we look at the table again and find the secant of 30 degrees to be 1.1547 inches as the length of the side.

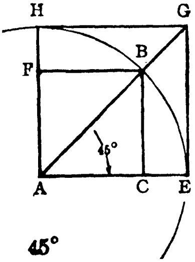


FIG. 4.—Showing 45-Degree Angles

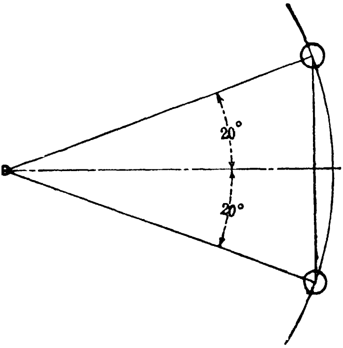


FIG. 5.—Spacing of Bolt Holes in a Circle

Suppose you have a square bar 2½ inches on each side: What is the distance across the corners? Looking at the second example, we see that the side of the square bar is represented by line *AE* and the corner distance by the secant *AD*, so we look for the secant of 45 degrees (because we know that half the 90-degree angle of a square bar must be 45 degrees) and find 1.4142, which would be the distance if the bar was 1 inch square. So we multiply 1.4142 by 2½ and get 3.5355 inches as the distance across the corners, and can know that this is closer than we can measure, and is not a guess by any means.

Reversing this we can find the side of a square that can be milled out of a round bar, such as the end of a reamer or tap. What square can we make on a 2-inch round reamer shank? The radius of the bar is the radius as *AB*, and the angle 45 degrees as before. Half the side of the square will be the sine *CB*, which the table shows to be 0.70711, and as this is half the chord which makes the flat across the bar, we multiply this by 2 and get 1.41422 inches as the distance across the flats for a reamer shank of this size.

Suppose we have a bar of 1½- by ¾-inch steel and want to find the distance across the corners and the angle it will make with the base. The 1½-inch side is the radius, the diagonal is the secant, and the ¾-inch side is the tangent of the angle. Reducing these to a basis of 1 inch, we have a bar 1 inch by ½ inch, and the ½ inch is the tangent of the angle. Looking in the table we find this to be almost exactly the tangent of 26 degrees and 34 minutes. With this angle the secant, or diagonal, is 1.1180 for a radius of 1 inch, and 1½ times this gives 1.6770 as the distance across corners.

A very practical use for this kind of calculation is in spacing bolt holes or otherwise dividing a circle into any number of equal parts. It is easy enough to get the length of each arc of the circumference by dividing 360 degrees by the number of divisions, but what we want is to find the chord, or the distance from one point to the next in a straight line, as a pair of dividers would step it off. First divide 360 by the number of divisions, say 9, and get 40 degrees in each part. Figure 5 shows this, and we want the distance shown, or the chord of the angle. This equals twice the sine of half the angle. Half the angle is 20 degrees, and the sine for this is 0.342. Twice this, or 0.684, is the chord of the 40-degree angle for every inch of radius. If the circle is 14 inches in diameter, the distance between the holes will be 7 × 0.684, or 4.788 inches. This is very quick and the most accurate method known.

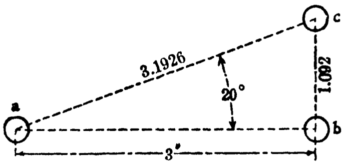


FIG. 6.—Laying Out Angles

Draftsmen often lay out jigs with the angles marked in degrees, as in Fig. 6, overlooking the fact that the toolmaker has no convenient or accurate protractor for measuring the angle. Assume that a drawing shows three holes, as *a*, *b*, and *c*, with *b* and *c* 20 degrees apart. The distance from *a* to *b* is 3 inches, what is the distance from *b* to *c* or from *a* to *c*?

As the known radius is from *a* to *b*, the distance *bc* is the tangent of the angle, and the tangent for a 1-inch radius is 0.36397, so for a 3-inch radius it is 3 × 0.36397 = 1.09191 (or 1.092 to three places) inches from *b* to *c* and at right angles to it.

But we need not depend on the accuracy of the square or of the way we use it, as we can find the distance from *a* to *c* just as easily and just as accurately as we did *bc*. This distance is the secant and is 1.0642 for a 1-inch radius. Multiplying this by 3 gives 3.1926 as the distance which can be accurately measured.

If the distance between *a* and *c* had been 3 inches, then *bc* would have been the sine and *ab* the cosine of the angle, both of which can be easily found from the tables.

It often happens that we want to find the angle of a roller or other piece of work, as in Fig. 7. Always work from the center line and continue the lines to complete the angle. Every triangle has three sides, and they are called the "side opposite," "side adjacent," and "hypotenuse," the first being opposite the angle, the second the base line, and the third the slant line.

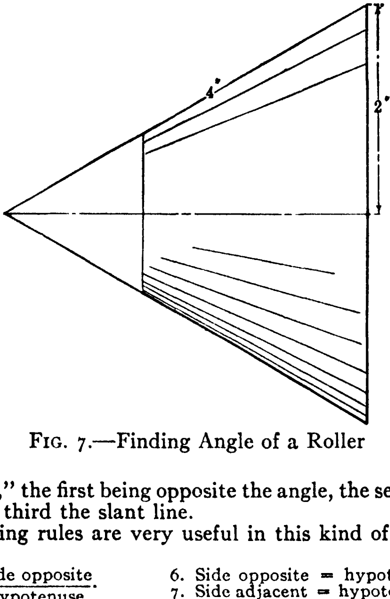


FIG. 7.—Finding Angle of a Roller

The following rules are very useful in this kind of work:

1. Sine $= \frac{\text{side opposite}}{\text{hypotenuse}}$.
2. Cosine $= \frac{\text{side adjacent}}{\text{hypotenuse}}$.
3. Tangent $= \frac{\text{side opposite}}{\text{side adjacent}}$.
4. Cotangent $= \frac{\text{side adjacent}}{\text{side opposite}}$.
5. Hypotenuse $= \frac{\text{side opposite}}{\text{sine}}$.
6. Side opposite = hypotenuse × sine.
7. Side adjacent = hypotenuse × cosine.
8. Side opposite = side adjacent × tangent.
9. Side adjacent = cotangent × side opposite.
10. Hypotenuse $= \frac{\text{side adjacent}}{\text{cosine}}$.

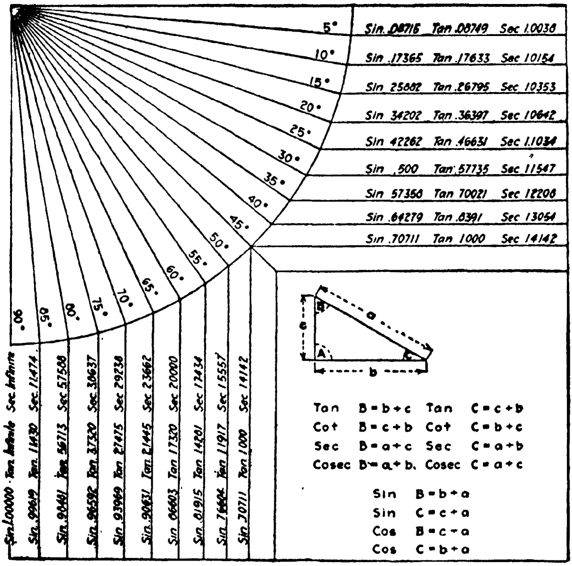
If we have the dimensions shown in Fig. 7, the side opposite, and the hypotenuse, we use formula 1, and dividing 2 by 4, we get ½ or 0.5 as the sine of the angle. The table shows this to be the sine of the angle of 30 degrees, consequently, this is a 30-degree angle.

Should it happen that we know only the hypotenuse and the angle, we use formula 6, and multiply 4 × 0.5 = 2, the side opposite. In the same way we can find the side adjacent by using formula 7. The cosine of 30 degrees is 0.866, and

$$4 \times 0.866 = 3.464$$

as the side adjacent.

Chart of Angles


5° Sin .08716 Tan .08749 Sec 1.0038
10° Sin .17365 Tan .17633 Sec 10154
15° Sin 25882 Tan .26795 Sec 10353
20° Sin 34202 Tan .36397 Sec 10642
25° Sin 42262 Tan .46631 Sec 1.1034
30° Sin .500 Tan .57735 Sec 11547
35° Sin 57358 Tan 70021 Sec 12208
40° Sin .64279 Tan .8391 Sec 13054
45° Sin .70711 Tan 1000 Sec 14142
50°
55°
60°
65°
70°
75°
80°
85°
90°
Sin 1.00000 Tan Infinite Sec Infinite
Sin .99619 Tan 11430 Sec 11.474
Sin .98481 Tan 56713 Sec 57588
Sin .96592 Tan 37320 Sec 38637
Sin .93969 Tan 27475 Sec 29238
Sin .90631 Tan 21445 Sec 23662
Sin 86603 Tan 17320 Sec 20000
Sin .81915 Tan 14281 Sec 17434
Sin .76604 Tan 11917 Sec 15557
Sin .70711 Tan 1000 Sec 14142
B
A
C
a
b
c
Tan B = b ÷ c Tan C = c ÷ b
Cot B = c ÷ b Cot C = b ÷ c
Sec B = a ÷ c Sec C = a ÷ b
Cosec B = a ÷ b. Cosec C = a ÷ c
Sin B = b ÷ a
Sin C = c ÷ a
Cos B = c ÷ a
Cos C = b ÷ a

This will save using the tables for angles in increments of an even 5 degrees.

LOCATING HOLE CENTERS AND OTHER TOOLROOM WORK

Any given hole may be selected as a checking point and the positions of all other holes referred to it for master measurements. Frequently, the toolmaker will find occasion to check center distances between holes that have no stipulated relationship to each other but do have an exact position in respect to some common point—say another hole center, and it may be desirable to find the correct distance across these two.

Both angles and center dimensions have to be considered. The hypotenuse of the triangle in Fig. 8 has a known dimension and is the radius, and the height is the sine. Note that it falls within the curve or arc of the circle. In Fig. 16 the base of the triangle is the radius, and the perpendicular side is the tangent, for it contacts the outside of the circle. The hypotenuse of the triangles in Figs. 8 to 14 is the radius, no matter in what position the triangle may be in respect to the horizontal line of the drawing. The perpendicular side or height of the triangle is the sine; the base of the triangle is the cosine. Various positions are shown to make the point clear.

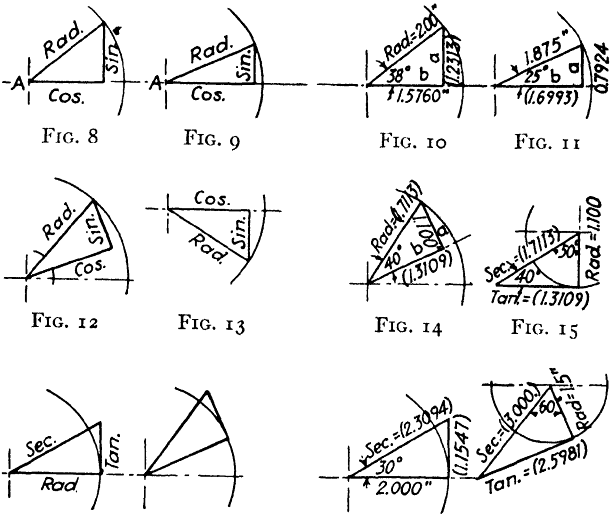


FIG. 8 FIG. 9 FIG. 10 FIG. 11

FIG. 12 FIG. 13 FIG. 14 FIG. 15

FIG. 16 FIG. 17 FIG. 18 FIG. 19

FIGS. 8 to 19.—NOTE: Values in Parentheses Are Computed

In Figs. 16 and 17 the base of the triangle is the radius and the height is the tangent; the slanting line connecting them, called the hypotenuse, becomes the secant. In Fig. 15 the perpendicular side or height is the known side and is used as the radius.

The arc of a circle in the sketches is merely to prevent possible confusion in regard to sines and tangents. Ordinarily, whichever line, base, or hypotenuse carries a known dimension is used as the radius for solution of the angles and lengths of other dimensions.

NOTE.—*In the following examples all calculated values are in parentheses.*

In Fig. 10, the radius is 2 inches, and the length of base (*b*) is 1.5760 inches. Dividing this by 2 to find the base line corresponding to 1 inch radius gives us 0.78801, and we find this quantity in the table of sines and cosines under cos 38°. The sine in the same double column is given as 0.61566, and we multiply this by 2 to give the length of this perpendicular side (*a*) when we have a radius of 2 inches. The result is 1.23132 inches.

In Fig. 11 we have an angle of 25 degrees and a radius of 1.875 inch. Reference to the table of sines will give, under the heading for 25 degrees, the quantity 0.42262 as the sine of that angle, and we multiply by 1.875 and secure the value 0.7924 inch. This is the length of side (*a*), while the length of base (*b*) is secured by multiplying cosine 0.90631 (for 25 degrees) by 1.875, which equals 1.69933 inches.

In Fig. 14 the center angle is 40 degrees, the base length (*b*) is unknown, but the height (*a*) is given as 1.100 inch. The sine of 40 degrees is given in a table of sines and cosines as 0.64279 to a radius of 1. If we divide 1.100 inch by 0.64279, we find the quotient to be 1.7113 inch as the radius or slope line of Fig. 14. Base (*b*) is found by multiplying the radius 1.7113 by cos 40°, or 0.76604. The result is 1.3109.

It is sometimes easier to solve a problem like Fig. 14 by working from the opposite angle. As the two acute angles equal 90 degrees, subtracting 40 degrees from 90 leaves 50 degrees as the center angle, Fig. 15. We may now consider our radius as struck from this point, and this radius is 1.100 inch. We select the value for the sloping side from a table of secants and find in the column for 50 degrees the value 1.15557. We multiply this by radius 1.100 and find the product to be 1.7113 inch, as that obtained by the method in Fig. 14. To find the base line in Fig. 15, we know the base line to be a tangent, and in the table of tangents, we find in the 50-degree column 1.19175 and multiply by 1.100, which gives 1.3109 inches for the length of base.

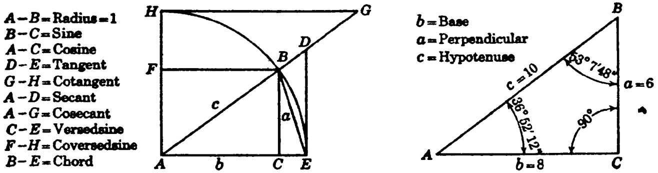
Figures 16 and 17 also show the relation of radius, secant, and tangent. Figure 18 shows the solution for base (or radius) of two inches, where secant and tangent are required for an angle of 30 degrees. Figure 19 shows a similar 30–60 degree problem with the height of the triangle taken as the radius equal to 1.500 inch. This is solved in the same way as the example in Fig. 15, that is, by referring to tables of secants and tangents and multiplying respective values for 60 degrees by 1.500 inch, giving 3.00 inches for the sloping side, or secant, and 2.5981 inches for the tangent.

Practical Applications

Figures 20 and 21 show typical tool jobs where jig bushings or die holes are to be located. Figure 20 (page 1208) is a case where, as in Figs. 10 to 14, we deal with sines and cosines. Figure 21, on the other hand, has the base line of the triangle as the radius, and we are dealing with tangent and secant for height and hypotenuse as in Figs. 16 to 19.

Not all tools to be bored have centers positioned in a right-angle triangle. But they admit of division into right-angle triangles and can then be treated as such.

Figure 22 is a layout with three holes whose center lines form a triangle with no right angle. Drop a perpendicular line from the



The Right-Angle Triangle

To Find	Knowing	Rule	Formula	Example
Angle A	Angles B and C	Subtract angle B from angle C...........	C − B = A	90° − 53° 7′ 48″ = 36° 52′ 12″
Angle B	Angles A and C	Subtract angle A from angle C...........	C − A = B	90° − 36° 52′ 12″ = 53° 7′ 48″
Angle C	Angles A and B	Add angle A to angle B.................	A + B = C	36° 52′ 12″ + 53° 7′ 48″ = 90°
Sine A	Sides a and c	Divide side a by side c..................	$\frac{a}{c}$ = sin A	$\frac{6}{10}$ = 0.60000 = sin 36° 52′ 12″
	Cosecant A	Divide 1 by cosecant A................	$\frac{1}{\text{cosec A}}$ = sin A	$\frac{1}{1.66666}$ = 0.60000 = sin 36° 52′ 12″
	Tangent A and cosine A	Multiply tangent A by cosine A..........	Tan A × cos A = sin A	0.75000 × 0.80000 = 0.60000 = sin 36° 52′ 12″

	Tangent A and secant A	Divide tangent A by secant A...........	$\frac{\text{Tan } A}{\sec A} = \sin A$	$\frac{0.75000}{1.25000} = 0.60000 = \sin 36^\circ 52' 12''$
	Cosine A and cotangent A	Divide cosine A by cotangent A..........	$\frac{\text{Cos } A}{\cot A} = \sin A$	$\frac{0.80000}{1.33333} = 0.60000 = \sin 36^\circ 52' 12''$
	Cosine A	Subtract the square of cosine A from 1 and extract the square root of the remainder..	$\sqrt{1 - \cos A^2} = \sin A$	$\sqrt{0.36} = 0.60000 = \sin 36^\circ 52' 12''$
Cosine A	Sides b and c	Divide side b by side c................	$\frac{b}{c} = \cos A$	$\frac{8}{10} = 0.80000 = \cos 36^\circ 52' 12''$
	Secant A	Divide 1 by secant A..................	$\frac{1}{\sec A} = \cos A$	$\frac{1}{1.25000} = 0.80000 = \cos 36^\circ 52' 12''$
	Cotangent A and sine A	Multiply cotangent A by sine A..........	$\text{Cot } A \times \sin A = \cos A$	$1.33333 \times 0.60000 = 0.80000 = \cos 36^\circ 52' 12''$
	Sine A and tangent A	Divide sine A by tangent A.............	$\frac{\text{Sin } A}{\tan A} = \cos A$	$\frac{0.60000}{0.75000} = 0.80000 = \cos 36^\circ 52' 12''$
	Cotangent A and cosecant A	Divide cotangent A by cosecant A........	$\frac{\text{Cot } A}{\text{cosec } A} = \cos A$	$\frac{1.33333}{1.66666} = 0.80000 = \cos 36^\circ 52' 12''$
	Sine A	Subtract the square of sine A from 1 and extract the square root of the remainder.	$\sqrt{1 - \sin A^2} = \cos A$	$\sqrt{0.64} = 0.80000 = \cos 36^\circ 52' 12''$

To Find	Knowing	Rule	Formula	Example
Tangent A	Sides a and b	Divide side a by side b	$\frac{a}{b} = \tan A$	$\frac{6}{8} = 0.75000 = \tan 36^\circ 52' 12''$
	Cotangent A	Divide 1 by cotangent A	$\frac{1}{\cot A} = \tan A$	$\frac{1}{1.33333} = 0.75000 = \tan 36^\circ 52' 12''$
	Secant A and sine A	Multiply secant A by sine A	$\sec A \times \sin A = \tan A$	$1.25000 \times 0.60000 = 0.75000 = \tan 36^\circ 52' 12''$
	Sine A and cosine A	Divide sine A by cosine A	$\frac{\sin A}{\cos A} = \tan A$	$\frac{0.60000}{0.80000} = 0.75000 = \tan 36^\circ 52' 12''$
	Secant A and cosecant A	Divide secant A by cosecant A	$\frac{\sec A}{\operatorname{cosec} A} = \tan A$	$\frac{1.25000}{1.66666} = 0.75000 = \tan 36^\circ 52' 12''$
	Secant A	Subtract 1 from the square of secant A and extract the square root of the remainder.	$\sqrt{\sec A^2 - 1} = \tan A$	$\sqrt{0.5625} = 0.75000 = \tan 36^\circ 52' 12''$
Cotangent A	Sides b and a	Divide side b by side a	$\frac{b}{a} = \cot A$	$\frac{8}{6} = 1.33333 = \cot 36^\circ 52' 12''$
	Tangent A	Divide 1 by tangent A	$\frac{1}{\tan A} = \cot A$	$\frac{1}{0.75000} = 1.33333 = \cot 36^\circ 52' 12''$
	Cosecant A and cosine A	Multiply cosecant A by cosine A	$\operatorname{cosec} A \times \cos A = \cot A$	$1.66666 \times 0.80000 = 1.33333 = \cot 36^\circ 52' 12''$

	Cosine A and sine A	Divide cosine A by sine A...............	$\frac{\text{Cos A}}{\text{sin A}} = \text{cot A}$	$\frac{0.80000}{0.60000} = 1.33333 = \text{cot } 36° 52' 12''$
	Cosecant A and secant A	Divide cosecant A by secant A...........	$\frac{\text{Cosec A}}{\text{sec A}} = \text{cot A}$	$\frac{1.66666}{1.25000} = 1.33333 = \text{cot } 36° 52' 12''$
	Cosecant A	Subtract 1 from the square of cosecant A and extract the square root of the remainder............................	$\sqrt{\text{Cosec A}^2 - 1} = \text{cot A}$	$\sqrt{1.77777} = 1.33333 = \text{cot } 36° 52' 12''$
Secant A	Sides c and b	Divide side c by side b.................	$\frac{c}{b} = \text{sec A}$	$\frac{10}{8} = 1.25000 = \text{sec } 36° 52' 12''$
	Cosine A	Divide 1 by cosine A..................	$\frac{1}{\text{cos A}} = \text{sec A}$	$\frac{1}{0.80000} = 1.25000 = \text{sec } 36° 52' 12''$
	Cosecant A and tangent A	Multiply cosecant A by tangent A.......	$\text{Cosecant A} \times \text{tan A} = \text{sec A}$	$1.66666 \times 0.75000 = 1.25000 = \text{sec } 36° 52' 12''$
	Tangent A and sine A	Divide tangent A by sine A..............	$\frac{\text{Tan A}}{\text{sin A}} = \text{sec A}$	$\frac{0.75000}{0.60000} = 1.25000 = \text{sec } 36° 52' 12''$
	Cosecant A and cotangent A	Divide cosecant A by cotangent A........	$\frac{\text{Cosec A}}{\text{cot A}} = \text{sec A}$	$\frac{1.66666}{1.33333} = 1.25000 = \text{sec } 36° 52' 12''$
	Tangent A	Add 1 to the square of tangent A and extract the square root of the sum.........	$\sqrt{\text{Tan A}^2 + 1} = \text{sec A}$	$\sqrt{1.5625} = 1.25000 = \text{sec } 36° 52' 12''$

To Find	Knowing	Rule	Formula	Example
Cosecant A	Sides c and a	Divide side c by side a	$\frac{c}{a} = \text{cosec A}$	$\frac{10}{6} = 1.66666 = \text{cosec } 36^\circ 52' 12''$
	Sine A	Divide 1 by sine A	$\frac{1}{0.60000} = \text{cosec A}$	$\frac{1}{0.60000} = 1.66666 = \text{cosec } 36^\circ 52' 12''$
	Secant A and cotangent A	Multiply secant A by cotangent A	$\text{Sec A} \times \text{cot A} = \text{cosec A}$	$1.25000 \times 1.33333 = 1.66666 = \text{cosec } 36^\circ 52' 12''$
	Secant A and tangent A	Divide secant A by tangent A	$\frac{\text{Sec A}}{\text{tan A}} = \text{cosec A}$	$\frac{1.25000}{0.75000} = 1.66666 = \text{cosec } 36^\circ 52' 12''$
	Cotangent A and cosine A	Divide cotangent A by cosine A	$\frac{\text{Cot A}}{\text{cos A}} = \text{cosec A}$	$\frac{1.33333}{0.80000} = 1.66666 = \text{cosec } 36^\circ 52' 12''$
	Cotangent A	Add I to the square of cotangent A and extract the square root of the sum	$\sqrt{\text{Cot A}^2 + \text{I}} = \text{cosec A}$	$\sqrt{2.77777} = 1.66666 = \text{cosec } 36^\circ 52' 12''$
Versed sine A	Sides c and b	Subtract side b from side c and divide the remainder by side c	$\frac{c - b}{c} = \text{versin A}$	$\frac{2}{10} = 0.20000 = \text{versin } 36^\circ 52' 12''$
	Cosine A	Subtract cosine A from 1	$1 - \text{cos A} = \text{versin A}$	$1 - 0.80000 = 0.20000 = \text{versin } 36^\circ 52' 12''$
Coversed sine A	Sides c and a	Subtract side a from side c and divide the remainder by side c	$\frac{c - a}{c} = \text{covers A}$	$\frac{4}{10} = 0.40000 = \text{covers } 36^\circ 52' 12''$
	Sine A	Subtract sin A from 1	$1 - \text{sin A}$	$1 - 0.60000 = 0.40000 = \text{covers } 36^\circ 52' 12''$

Chord A	Sine ½ A	Multiply the sine of half the angle A by 2 and by the radius or side c	$2c \sin \frac{A}{2} = \text{chord } A$	Sin 18° 26′ 6″ = 0.31623 $0.31623 \times 2 \times 10 = 6.3246$ = chord 36° 52′ 12″
Side a	Sides c and b	Subtract the square of side b from the square of side c and extract the square root of the remainder	$\sqrt{c^2 - b^2} = \text{side } a$	$\sqrt{36} = 6 = \text{side } a$
	Side c and sine A	Multiply side c by sine A	$c \times \sin A = \text{side } a$	$10 \times 0.60000 = 6 = \text{side } a$
	Side b and tangent A	Multiply side b by tangent A	$b \times \tan A = \text{side } a$	$8 \times 0.75000 = 6 = \text{side } a$
	Side b and cotangent A	Divide side b by cotangent A	$\frac{b}{\cot A} = \text{side } a$	$\frac{8}{0.13333} = 6 = \text{side } a$
	Side c and cosecant A	Divide side c by cosecant A	$\frac{c}{\operatorname{cosec} A} = \text{side } A$	$\frac{10}{1.66666} = 6 = \text{side } a$
Side b	Sides c and a	Subtract the square of side a from the square c and extract the square root of the remainder	$\sqrt{c^2 - a^2} = \text{side } b$	$\sqrt{64} = 8 = \text{side } b$
	Side c and cosine A	Multiply side c by cosine A	$c \times \cos A = \text{side } b$	$10 \times 0.80000 = 8 = \text{side } b$
	Side a and cotangent A	Multiply side a by cotangent A	$a \times \cot A = \text{side } b$	$6 \times 1.33333 = 8 = \text{side } b$
	Side a and tangent A	Divide side a by tangent A	$\frac{a}{\tan A} = \text{side } b$	$\frac{6}{0.7500} = 8 = \text{side } b$
	Side c and secant A	Divide side c by secant A	$\frac{c}{\sec A} = \text{side } b$	$\frac{10}{1.25000} = 8 = \text{side } b$

To Find	Knowing	Rule	Formula	Example
Side c	Sides a and b	Add the square of side a to the square of side b and extract the square root of the sum	$\sqrt{a^2 + b^2}$ = side c	$\sqrt{6^2 + 8^2} = \sqrt{36 + 64} = \sqrt{100} = 10$ = side c
	Side b and secant A	Multiply side b by secant A	b × sec A = side c	8 × 1.25000 = 10 = side c
	Side a and cosecant A	Multiply side a by cosecant A	a × cosec A = side c	6 × 1.66666 = 10 = side c
	Side a and sine A	Divide side a by sine A	$\frac{a}{\sin A}$ = side c	$\frac{6}{0.60000} = 10$ = side c
	Side b and cosine A	Divide side b by cosine A	$\frac{b}{\cos A}$ = side c	$\frac{8}{0.80000} = 10$ = side c
	Sides c and b and versed sine A	Subtract side b from side c and divide the remainder by versed sine A	$\frac{c - b}{\text{vers } A}$ = side c	$\frac{2}{0.20000} = 10$ = side c
	Sides c and a and coversed sine A	Subtract side a from side c and divide the remainder by coversed sine A	$\frac{c - a}{\text{covers } A}$ = side c	$\frac{4}{0.40000} = 10$ = side c

apex, dividing the figure into 2 right-angled triangles. The lengths of these three sides are given, but the base line is now to be divided into its two parts b and b', and we can at the same time get height h. The base line is given as 2.875 inches. We divide it into b and b' as follows: Multiply the sum and difference of the two other sides and divide the product by the base line. The quotient will be the difference between the two sections b and b'. Thus: (2.00 inches plus 1.125 inches) × (2.00 − 1.125) equals 3.125 inches × 0.875 = 2.7344 inches. Dividing 2.7344 inches by 2.875 equals 0.9511 inch. This is the difference in lengths of lines b and b'. If we subtract half of this difference from half of base line 2.875 inches, we have 1.4375 − 0.4755 = 0.9620, which is the length of the short line b. Subtracting this from 2.875 inches gives 1.9130 inches as the longer line b'. The height h and the angles can now be found as in the case of any right-angle triangle.

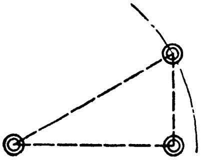


FIG. 20

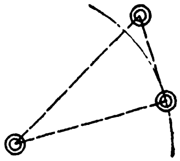


FIG. 21

The triangle at the left in Fig. 22 has a base line of 0.9620 to a radius of 1.125 inches. Dividing 0.9620 by 1.125 gives us, for a 1-inch radius, a base line of 0.8551 inch. This is the cosine, and in a table of cosines we find that the corresponding angle is 31 degrees 14 minutes. The sine is given as 0.5185 (this is, of course, to a radius of 1). Multiplying 0.5185 by 1.125 (the radius of our triangle) we find the sine, or height h, to be 0.5833 inch.

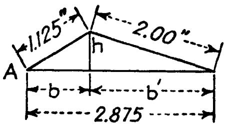


FIG. 22.—Computed: b = 0.9620 Inch; b' = 1.9130 Inches; h = 0.5833 Inch; Angle A Is 31 Degrees 14 Minutes; Angle b' Is 16 Degrees 57½ Minutes

Simple Solutions of Right-Angle-Triangle Problems for Mechanics

To enable those who have a knowledge of arithmetic only to find easily the different dimensions of the right-angle triangle, this table was prepared by S. A. Hand, associate editor of *American Machinist.*

The particular angle chosen for illustration was selected on account of the ease with which the dimensions of the sides could be found by simple arithmetic.

The beginner will, of course, understand that dimensions of the sides of the triangle can be any other than those given in the illustration, but their proportions will remain constant for the same angle.

Complete tables of sines, tangents, secants, etc., will be found on pages 1219 to 1253.

TESTING ANGLES WITH PLUGS

A 60-degree angle for all corners of a gage gives a triangle with three sides equal (see Fig. 23). The diameter of a plug that will contact the three sides is found by the formula $D = W \tan 30^\circ$. Or, diameter equals length of one side times tangent of 30 degrees. tan 30° to a radius of 1 is 0.57735. With W equal to 2 inches, the diameter of the plug will be 2×0.57735 or 1.15470 inches.

Taking the different examples in Fig. 23, thus, 20, 30, and 45 degrees, for included angle A, a formula may be written as follows:

$$D = W \tan (45^\circ - A/4)$$

where D = diameter of plug.
W = width of V opening.
A = the included angle of the V″.

Consider in Fig. 23 the V with 20 degrees included angle: 45 degrees $- \frac{A}{4} = 45$ degrees $- 5 = 40$ degrees. $\tan 40^\circ = 0.83910$. If W is taken as 1 inch, then $D = 1 \times 0.83910$. So for any angle where width W is 1 inch, the diameter of the plug to come flush with the top of the V opening will be taken directly as $\tan \left(45^\circ - \frac{A}{4}\right)$. The width 1 inch is convenient for many cases where the toolmaker is interested only in the angle at the bottom of the V and not necessarily in its width at the top.

It is often required to establish an accurate angle for gaging various tools and templets where the depth of the V and the width of the opening are only important in producing the desired angle of V. It is difficult to measure accurately the width W without a toolmaker's microscope, but with the plug it is simplified. A 1-inch width of opening is convenient for many angles, but where a smaller one is desired, the formula is used by taking any convenient value for W.

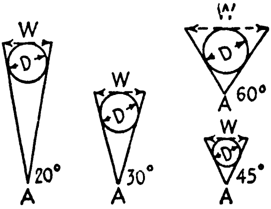


FIG. 23.

Right-Angle Triangles

Figures 24 to 30*a* show a number of ways in which right-angle triangles enter into tool and gage work. If we know the length of side b and the angle A, we can multiply b by tan A to find side a. If side c is known, we find side a is equal to side $c \times \sin A$. If angle B is known and side a, then side $a \times \tan B$ will give side b. With sides a and b known, then side c equals $\sqrt{a^2 + b^2}$. If angle A is known, subtract it from 90 degrees to obtain angle B. Or if B is given, subtract it from 90 degrees to obtain angle A.

A simple rule for obtaining the diameter of a plug to contact all three sides of a right-angle triangle is to add the two shorter sides (as a and b; Figs. 24 and 30a) and subtract c from their sum. Try this with the well-known right-angle proportions of 3, 4, and 5 inches for the three sides: $3 + 4 = 7$; $7 - 5 = 2$ inches, the exact diameter of a circle to contact all three sides.

In Fig. 24 or Fig. 30a assume angle A to be 30 degrees and side b to be 1.30 inches. What is the diameter of a plug to contact sides a, b, and c?

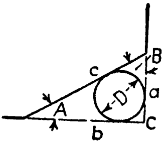


FIG. 24.

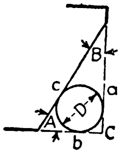


FIG. 25.

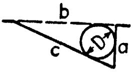


FIG. 26.

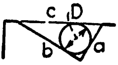


FIG. 27.

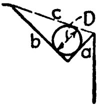


FIG. 28.

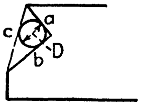
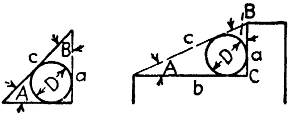


FIG. 29.



FIGS. 30 and 30a. (See formulas on page 1212.)

Tangent of angle A is tan 30° or 0.57735. So side a is $0.57735 \times 1.3 = 0.75056$ inch. Sec $30^\circ = 1.1547 \times 1.3 = 1.5011$ inches as the length of line c. Then $a + b = 0.75056 + 1.3$ inches $= 2.0506$ inches. Subtracting c or 1.5011, leaves 0.5495 as the diameter of the circle or plug.

Or, working this arithmetically by the squares of the sides and the square root of the sum, it will work out as follows:

$$\begin{aligned} a^2 &= 0.56334 \\ b^2 &= 1.69 \\ a^2 + b^2 &= 2.25334 \end{aligned}$$

$\sqrt{2.25334} = 1.5011$ for side c, the same as obtained by the trig method above.

Another Method of Calculating Plug Diameter

To get the diameter of the cylinder or plug for a right angle job like those in Figs. 24 to 30a without using more than the length of side b and angle A, we can use the formula $D = \dfrac{2b}{\left(\cot \frac{A}{2}\right) + 1}$.

A drawing does not always give other dimensions than this distance b and a single angle only (angle A), leaving other figuring for the shopman in case he wants to make further calculations.

Applying the formula to the problem already worked out by the other methods, we have $a = 1.3$ inches × 2 = 2.6 inches. Then

$$D = \frac{2.6}{\left(\cot\frac{A}{2}\right) + 1} = \frac{2.6}{(\cot 15^\circ) + 1} = \frac{2.6}{4.73205} = 0.5495 \text{ inch.}$$

A series of formulas, arithmetical and trigonometrical, are given in the table on page 1212. These are self-explanatory. They cover most conditions that arise with right-angle-triangle problems.

Other Angles than Right Angles

Angular gage work and similar jobs with angles greater or less than 90 degrees are shown in Figs. 31 and 32. The angles A, B, and C, Fig. 31, are respectively 40 degrees, 68 degrees, and 72 degrees. All of these may be known, or two of them known and the other found by subtracting the sum of the two from 180 degrees for the third angle. In any event the formula used for the diameter of a cylinder or plug (D) to fill the angle and contact the three sides is:

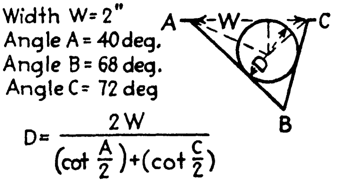


FIG. 31.

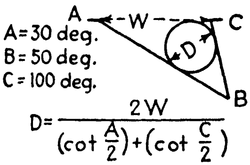


FIG. 32.

$$D = \frac{2W}{\left(\cot\frac{A}{2}\right) + \left(\cot\frac{C}{2}\right)}$$

Then

$$D = \frac{4}{\cot 20^\circ + \cot 36^\circ},$$

or

$$D = \frac{4}{2.74748 + 1.37638} = \frac{4}{4.12386} = 0.9698 \text{ inch.}$$

The angular gage opening in Fig. 32 is calculated for the diameter of the contacting plug by the same method and formula as used in connection with the one in Fig. 31.

FORMULAS FOR RIGHT ANGLE TRIANGLES
(Page 1210)

To Find	Knowing	Formula
Side a	Sides b and c	$\sqrt{c^2 - b^2}$ = side a
Side b	Sides a and c	$\sqrt{c^2 - a^2}$ = side b
Side c	Sides a and b	$\sqrt{a^2 + b^2}$ = side c
Angle A	Angle B	$90° - B = A$
Angle B	Angle A	$90° - A = B$
Sides a and b	Angle A and side c	$c \times \sin A$ = side a $c \times \cos A$ = side b
Sides a and b	Angle B and side c	$c \times \cos B$ = side a $c \times \sin B$ = side b
Sides a and c	Angle A and side b	$b \times \tan A$ = side a $b \times \sec A$ = side c
Sides b and c	Angle B and side a	$a \times \tan B$ = side b $a \times \sec B$ = side c
Diameter of Plug D	Sides a, b, and c	$(a + b) - c$ = Dia. D

LAYING OUT REGULAR POLYGONS

The cut-and-try method is to draw a circle and space it off, but it saves time to know what spacing to use or how large a circle to

TABLE OF REGULAR POLYGONS

Number of Sides	Name of Figure	Diameter of Circle that will just enclose when side is 1	Diameter of circle that will just go inside when side is 1	Length of side where diameter of enclosure circle equals 1	Length of side where inside circle equals 1	Angle formed by lines drawn from center to corners	Angle formed by outer sides of figures	To find Area of Figure multiply side by itself and by number in this column
3	Triangle ..	1.1546	.5774	.866	1.732	120°	60°	.4330
4	Square	1.4142	1.	.7071	1.	90	90	1.
5	Pentagon ..	1.7012	1.3764	.5878	.7265	72	108	1.7204
6	Hexagon ..	2.	1.732	.5	.5774	60	120	2.5980
7	Heptagon .	2.3048	2.0766	.4338	.4815	51°-26′	$128\frac{4}{7}$	3.6339
8	Octagon...	2.6132	2.4142	.3827	.4142	45	135	4.8284
9	Nonagon ..	2.9238	2.7474	.342	.3639	40	140	6.1818
10	Decagon ..	3.236	3.0776	.309	.3247	36	144	7.6942
11	Undecagon	3.5494	3.4056	.2817	.2936	32°-43	$147\frac{8}{11}$	9.3656
12	Dodecagon	3.8638	3.732	.2588	.2679	30	150	11.1961

draw to get a figure of the right size. Suppose we wish to lay out any regular figure, such as a pentagon or five-sided figure, having sides 1½ inches long.

Using the Table

Looking in the third column, we find "Diameter of circle that will just enclose it," and opposite pentagon we find 1.7012 as the circle that will just enclose a pentagon having a side equal to 1. This may be 1 inch or 1 anything else, so, as we are dealing in inches, we call it inches. As the side of the pentagon is to be 1½ inches, we multiply 1.7012 by 1½ and get 2.5518 as the diameter of circle to draw, and take half of this, or the radius 1.2759, in the compass to draw the circle. Then with 1½ inches in the dividers, we space around the circle, and if the work has been carefully done, it will just divide it into five equal parts. Connect these points by straight lines, and you have a pentagon with sides 1½ inches long.

If the pentagon is to go inside a circle of given diameter, say 2 inches, look under column 5, which gives "Length of side when diameter of enclosing circle equals 1," and find 0.5878. Multiply by 2 as this is for a 2-inch circle, and the side will be 2 × 0.5878 = 1.1756. Take this distance in the dividers and step around the 2-inch circle.

Assume that it is necessary to have a triangular end on a round shaft, how large must the shaft be to give a triangle 1.5 inches on a side?

Look in the table under column 3, and opposite triangle, find 1.1546, meaning that where the side of a triangle is 1, the diameter of a circle that will just enclose it is 1.1546. As the side is 1.5, we have 1.5 × 1.1546 = 1.7318, the diameter of the shaft required. If the corners need not be sharp, probably a shaft 1.625 would be ample.

Reversing this to find the size of a bearing that can be turned on a triangular bar of this size, look in column 4, which gives the largest circle that will go inside a triangle with a side equal to 1. This gives 0.5774. Multiplying 0.5774 by 1.5 = 0.8661.

A square taper reamer is to be used which must ream 1 inch at the small end and 1.5 at the back. What size must this be across the flats at both places?

Under column 5 find 0.7071 as the length of the side of a square when the diameter of the enclosing circle is 1, so that this will be the side of the small end of the reamer, and 1.5 × 0.7071 = 1.0606, the side of the reamer at the large end.

FINDING THE DIAMETER WITHOUT THE CENTER

It sometimes happens in measuring up a machine that we need to know the radius of curves when the center is not accessible. Three such cases are shown in Figs. 33, 34, and 35, the first two being a machine and the last a broken pulley. In Fig. 33, the rule is short enough to go in the curve, but in Fig. 34, it has one end touching and the other across the sides. It makes no difference which is used so long as the distances are measured correctly, the short distance, or *versed sine,* being taken at the exact center of the chord and at right angles to it. It is easier figuring when the chord or the height is even inches, so in measuring, slip the rule until one or the other comes even; sometimes it is better to make the height come 1 inch and let the chord go as it will, but at others, the reverse may be true. The rule for finding the diameter is: Square half the chord, add to this the square of the height, and divide the whole thing by the height.

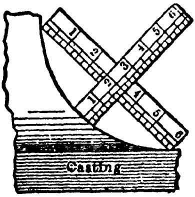


FIG. 33

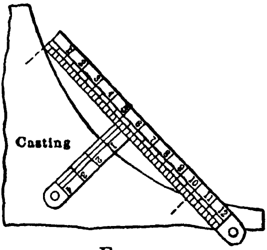


FIG. 34

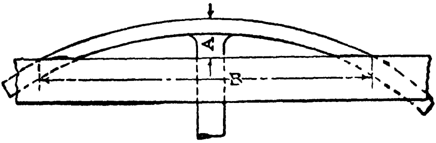


FIG. 35

If the chord is 6 inches, as in Fig. 33, and the height $1\frac{1}{2}$ inches, we have

$$\frac{(\frac{1}{2}\text{ chord})^2 + \text{height}^2}{\text{height}} = \frac{3^2 + 1\frac{1}{2}^2}{1\frac{1}{2}} = \frac{9 + 2\frac{1}{4}}{1\frac{1}{2}} = \frac{11\frac{1}{4}}{1\frac{1}{2}} = 7\frac{1}{2}\text{ inches.}$$

Or, as in Fig. 34, call the chord 10 inches and the height 1 inch, then the figures are

$$\frac{5^2 + 1^2}{1} = \frac{25 + 1}{1} = 26\text{ inches.}$$

In Fig. 35 we have a piece of broken pulley, and we find the chords *B* to be 24 inches and the height *A* to be 2 inches. This becomes $\frac{12^2 + 2^2}{2} = \frac{144 + 4}{2} = \frac{148}{2} = 74$, so that the diameter of the pulley is 74 inches.

Flat-Square Method

However, the method described is approximate only, because the measurement of the height will usually fall in decimals that cannot be read by scale, and a very small error in the height will be greatly multiplied in the resulting diameter. For example: with a chord of 10 inches and a height of 1 inch, as in Fig. 34, an error of 0.01 inch in the height will make a difference of about $\frac{1}{4}$ inch in the diameter. Then, too, it is difficult to measure the chord accurately with a scale. For greater accuracy, the height should be measured by a depth micrometer.

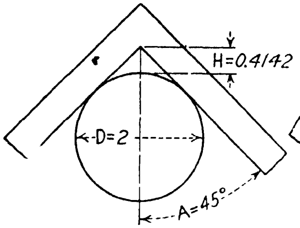


FIG. 36

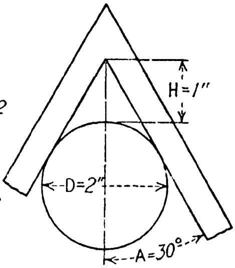


FIG. 37

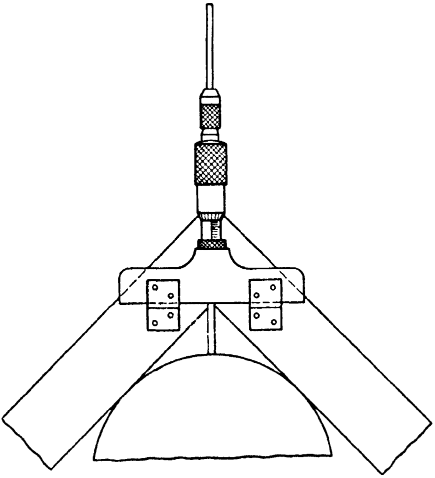


FIG. 38

For outside measurements, a better method is to use a flat square, as in Fig. 36. In this case, the height *H* from the surface of the work to the inside apex of the square multiplied by 4.8286 equals the diameter of the work. When great accuracy is required, as in sizing gear segments, an instrument having legs at an included angle of 60 degrees, as in Fig. 37, should be used. With such an instrument, the height H is always equal to one-half the diameter of the work, so that to find the diameter, the height must be multiplied by two. Either of these instruments can have a micrometer height gage attached for greater accuracy in reading the height, as in Fig. 38, or the height can be measured by an inside micrometer having a pointed rod.

With an instrument having legs at any included angle, the cosecant of half the included angle is always equal to the distance between the center of the work and the inner apex of the angle. Thus, a constant by which to multiply the height H to find the diameter D can be found by subtracting 1 from the cosecant of half the included angle and dividing 2 by the remainder, thus: $\frac{2}{\text{cosecant angle } A - 1}$.

EXAMPLE.—In an instrument having legs at an included angle of 90 degrees, as in Fig. 36, the angle A is 45 degrees, the cosecant of which is 1.4142. If the height H is 0.4142 inch, then $\frac{2}{1.4142} - - 1 = 4.8286$, and the height (0.4142 inch) multiplied by 4.8286 = 2 inches, and this is the diameter of the work.

In an instrument having legs at an included angle of 60 degrees, as in Fig. 37, the angle A is 30 degrees, the cosecant of which is 2. If the height H is 1 inch, then $\frac{2}{2 - 1} = 2$, and the height (1 inch) multiplied by 2 = 2 inches, which is the diameter D of the work.

When using such instruments for very accurate work, it is always well to calibrate them by using a gage or a disk of known diameter and as near the size of the work as possible.

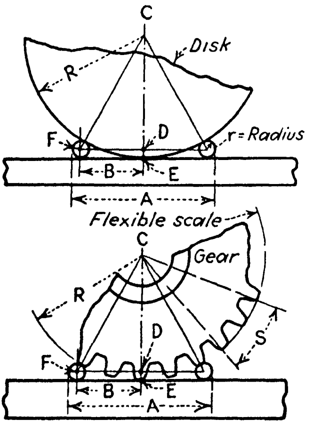


FIG. 39

Another Method

Another method, suggested by Charles Kugler, is to stand the fragment of either pulley or gear on a flat plate, as in Fig. 39. Place two pieces of drill rod in the plate in contact with the face of the fragment, as shown in the illustration, and fasten them to the plate with a few drops of solder. Remove the fragment and measure the distance across the pieces of drill rod with a micrometer.

Let A = the micrometer measurement across the pieces of drill rod.
r = the radius of the drill rod.
R = the radius of the whole disc or gear.

$$B = \frac{A - 2r}{2}.$$

Then $$R = \frac{B^2}{4r}.$$

Since lines drawn through the points *CDF* form a right-angle triangle, the formula can be proved as follows:

$$(CF)^2 = (CD)^2 + (DF)^2,$$

and $$CF = R + r.$$

$$CD = R - DE, \quad \text{or} \quad CD = R - r.$$

$$(R + r)^2 = (R - r)^2 + B^2.$$

$$R^2 + 2Rr + r^2 = R^2 - 2Rr + r^2 + B^2.$$

Therefore $$4Rr = B^2 \quad \text{and} \quad R = \frac{B^2}{4r}.$$

If the fragment is that of a gear, having found the diameter of the whole by multiplying the radius by 2, the diametral pitch can be found by placing the fragment on such a gear chart as can be found in the Brown and Sharpe small-tool catalog. Having these two items, all other data can be calculated. In the absence of a gear chart, two points, such as are included in the dimension *S*, are selected at random and are measured with a flexible scale, and the number of teeth between them is counted.

Let H = the circumference of the gear.
S = the distance between the two points on the periphery.
F = the number of teeth in the distance *S*.
W = the ratio between the circumference and the distance *S*.

Then $H = W$, and $W \times F$ = the number of teeth in the whole gear, because the ratio between the circumference of the gear and the distance *S* is the same as that between the number of teeth in the distance *S* and the number of teeth in the gear. With the outside diameter of the gear and the number of teeth known, all other data can be easily found.

This method will be found very useful in job shops which replace broken gears.

PROPERTIES OF REGULAR FIGURES

The Circle

A circle is a continuous curved line having every point at an equal distance from the center.

Perimeter, or circumference, is always 3.14159265359 times the diameter, although 3.1416 is generally used and $3\frac{1}{7}$ is a very close approximation.

Area equals the diameter squared × 0.7854, or half the diameter squared × 3.1416, or half the diameter × half the circumference.

Diameter of a square having equal area = diameter of circle × 0.886 very nearly.

Triangle

An equilateral triangle is a regular figure having three equal sides and three equal angles of 60 degrees each.

Side = 0.866 × the diameter of enclosing circle.

Distance from one side to opposite point = the side × 0.866, or diameter of enclosing circle × 0.75, or inside circle × 1⅓.

Diameter of enclosing circle = the side × 1.1546, or 1⅓ × distance from side to point or twice inside circle.

Diameter of inside circle = side × 0.5774 or ½ the enclosing circle.

Area = one side multiplied by itself and by 0.433013.

Diameter of circle having equal area = side of triangle × 0.73.

The Square

A square is a figure with four equal sides and four equal angles of 90 degrees.

Perimeter, or outside surface, is four times the length of one side.

Area = one side × the other, which is the same as multiplying by itself or "squaring."

Diagonal, or "long diameter," or "distance across corners," = the side × 1.414.

Area of circle that will go inside the square = one side × itself × 0.7854, or 0.7854 × the area of the square.

Area of circle that will just enclose the square = diagonal × itself × 0.7854, or 1.27 × the area of the square.

Diameter of a circle having an equal area = 1.126, or practically 1⅛ × the side of the square.

The Hexagon

A hexagon is a regular figure with six equal sides and six equal angles of 120 degrees. It can be drawn inside a circle by spacing around with the radius of the circle.

Side = ½ the diameter of enclosing circle.

Long diameter = diameter of enclosing circle, or twice the length of one side.

Short diameter = the long diameter × 0.866, or 1.732 × one side.

Area = one side × itself × 2.5981.

Area of enclosing circle = one side × itself × 3.1416.

Area of an inside circle = the short diameter × itself × 0.7854.

Diameter of circle having equal area = practically 0.9 × long diameter.

The Octagon

An octagon is a regular figure with eight equal sides and eight equal angles of 135 degrees.

Side = the long diameter × 0.382.

Side = the short diameter × 0.415.

Long diameter = diameter of enclosing circle, or one side × 2.62.

Short diameter = the long diameter × 0.93, or one side × 2.414.

Area = one side × itself × 4.8284.

Area of enclosing circle = 1.126 × area of octagon.

Area of inside circle = 0.972 × area of octagon.

The diameter of a circle having equal area = 0.953 × the long diameter of the octagon.

	0°		1°		2°		3°		
′	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	′
0	.00000	Infinite.	.01746	57.2900	.03492	28.6363	.05241	19.0811	60
1	.00029	3437.750	.01775	56.3506	.03521	28.3994	.05270	18.9755	59
2	.00058	1718.870	.01804	55.4415	.03550	28.1664	.05299	18.8711	58
3	.00087	1145.920	.01833	54.5613	.03579	27.9372	.05328	18.7678	57
4	.00116	859.436	.01862	53.7086	.03609	27.7117	.05357	18.6656	56
5	.00145	687.549	.01891	52.8821	.03638	27.4899	.05387	18.5645	55
6	.00175	572.957	.01920	52.0807	.03667	27.2715	.05416	18.4645	54
7	.00204	491.106	.01949	51.3032	.03696	27.0566	.05445	18.3655	53
8	.00233	429.718	.01978	50.5485	.03725	26.8450	.05474	18.2677	52
9	.00262	381.971	.02007	49.8157	.03754	26.6367	.05503	18.1708	51
10	.00291	343.774	.02036	49.1039	.03783	26.4316	.05533	18.0750	50
11	.00320	312.521	.02066	48.4121	.03812	26.2296	.05562	17.9802	49
12	.00349	286.478	.02095	47.7395	.03842	26.0307	.05591	17.8863	48
13	.00378	264.441	.02124	47.0853	.03871	25.8348	.05620	17.7934	47
14	.00407	245.552	.02153	46.4489	.03900	25.6418	.05649	17.7015	46
15	.00436	229.182	.02182	45.8294	.03929	25.4517	.05678	17.6106	45
16	.00465	214.858	.02211	45.2261	.03958	25.2644	.05708	17.5205	44
17	.00495	202.219	.02240	44.6386	.03987	25.0798	.05737	17.4314	43
18	.00524	190.984	.02269	44.0661	.04016	24.8978	.05766	17.3432	42
19	.00553	180.932	.02298	43.5081	.04046	24.7185	.05795	17.2558	41
20	.00582	171.885	.02328	42.9641	.04075	24.5418	.05824	17.1693	40
21	.00611	163.700	.02357	42.4335	.04104	24.3675	.05854	17.0837	39
22	.00640	156.259	.02386	41.9158	.04133	24.1957	.05883	16.9990	38
23	.00669	149.465	.02415	41.4106	.04162	24.0263	.05912	16.9150	37
24	.00698	143.237	.02444	40.9174	.04191	23.8593	.05941	16.8319	36
25	.00727	137.507	.02473	40.4358	.04220	23.6945	.05970	16.7496	35
26	.00756	132.219	.02502	39.9655	.04250	23.5321	.05999	16.6681	34
27	.00785	127.321	.02531	39.5059	.04279	23.3718	.06029	16.5874	33
28	.00814	122.774	.02560	39.0568	.04308	23.2137	.06058	16.5075	32
29	.00844	118.540	.02589	38.6177	.04337	23.0577	.06087	16.4283	31
30	.00873	114.589	.02619	38.1885	.04366	22.9038	.06116	16.3499	30
31	.00902	110.892	.02648	37.7686	.04395	22.7519	.06145	16.2722	29
32	.00931	107.426	.02677	37.3579	.04424	22.6020	.06175	16.1952	28
33	.00960	104.171	.02706	36.9560	.04454	22.4541	.06204	16.1190	27
34	.00989	101.107	.02735	36.5627	.04483	22.3081	.06233	16.0435	26
35	.01018	98.2179	.02764	36.1776	.04512	22.1640	.06262	15.9687	25
36	.01047	95.4895	.02793	35.8006	.04541	22.0217	.06291	15.8945	24
37	.01076	92.9085	.02822	35.4313	.04570	21.8813	.06321	15.8211	23
38	.01105	90.4633	.02851	35.0695	.04599	21.7426	.06350	15.7483	22
39	.01135	88.1436	.02881	34.7151	.04628	21.6056	.06379	15.6762	21
40	.01164	85.9398	.02910	34.3678	.04658	21.4704	.06408	15.6048	20
41	.01193	83.8435	.02939	34.0273	.04687	21.3369	.06437	15.5340	19
42	.01222	81.8470	.02968	33.6935	.04716	21.2049	.06467	15.4638	18
43	.01251	79.9434	.02997	33.3662	.04745	21.0747	.06496	15.3943	17
44	.01280	78.1263	.03026	33.0452	.04774	20.9460	.06525	15.3254	16
45	.01309	76.3900	.03055	32.7303	.04803	20.8188	.06554	15.2571	15
46	.01338	74.7292	.03084	32.4213	.04832	20.6932	.06584	15.1893	14
47	.01367	73.1390	.03114	32.1181	.04862	20.5691	.06613	15.1222	13
48	.01396	71.6151	.03143	31.8205	.04891	20.4465	.06642	15.0557	12
49	.01425	70.1533	.03172	31.5284	.04920	20.3253	.06671	14.9898	11
50	.01455	68.7501	.03201	31.2416	.04949	20.2056	.06700	14.9244	10
51	.01484	67.4019	.03230	30.9599	.04978	20.0872	.06730	14.8596	9
52	.01513	66.1055	.03259	30.6833	.05007	19.9702	.06759	14.7954	8
53	.01542	64.8580	.03288	30.4116	.05037	19.8546	.06788	14.7317	7
54	.01571	63.6567	.03317	30.1446	.05066	19.7403	.06817	14.6685	6
55	.01600	62.4992	.03346	29.8823	.05095	19.6273	.06847	14.6059	5
56	.01629	61.3829	.03376	29.6245	.05124	19.5156	.06876	14.5438	4
57	.01658	60.3058	.03405	29.3711	.05153	19.4051	.06905	14.4823	3
58	.01687	59.2659	.03434	29.1220	.05182	19.2959	.06934	14.4212	2
59	.01716	58.2612	.03463	28.8771	.05212	19.1879	.06963	14.3607	1
60	.01746	57.2900	.03492	28.6363	.05241	19.0811	.06993	14.3007	0
′	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	′
	89°		88°		87°		86°		

′	4°		5°		6°		7°		′
′	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.	′
0	.06993	14.3007	.08749	11.4301	.10510	9.51436	.12278	8.14435	60
1	.07022	14.2411	.08778	11.3919	.10540	9.48781	.12308	8.12481	59
2	.07051	14.1821	.08807	11.3540	.10569	9.46141	.12338	8.10536	58
3	.07080	14.1235	.08837	11.3163	.10599	9.43515	.12367	8.08600	57
4	.07110	14.0655	.08866	11.2789	.10628	9.40904	.12397	8.06674	56
5	.07139	14.0079	.08895	11.2417	.10657	9.38307	.12426	8.04756	55
6	.07168	13.9507	.08925	11.2048	.10687	9.35724	.12456	8.02848	54
7	.07197	13.8940	.08954	11.1681	.10716	9.33154	.12485	8.00948	53
8	.07227	13.8378	.08983	11.1316	.10746	9.30599	.12515	7.99058	52
9	.07256	13.7821	.09013	11.0954	.10775	9.28058	.12544	7.97176	51
10	.07285	13.7267	.09042	11.0594	.10805	9.25530	.12574	7.95302	50
11	.07314	13.6719	.09071	11.0237	.10834	9.23016	.12603	7.93438	49
12	.07344	13.6174	.09101	10.9882	.10863	9.20516	.12633	7.91582	48
13	.07373	13.5634	.09130	10.9529	.10893	9.18028	.12662	7.89734	47
14	.07402	13.5098	.09159	10.9178	.10922	9.15554	.12692	7.87895	46
15	.07431	13.4566	.09189	10.8829	.10952	9.13093	.12722	7.86064	45
16	.07461	13.4039	.09218	10.8483	.10981	9.10646	.12751	7.84242	44
17	.07490	13.3515	.09247	10.8139	.11011	9.08211	.12781	7.82428	43
18	.07519	13.2996	.09277	10.7797	.11040	9.05789	.12810	7.80622	42
19	.07548	13.2480	.09306	10.7457	.11070	9.03379	.12840	7.78825	41
20	.07578	13.1969	.09335	10.7119	.11099	9.00983	.12869	7.77035	40
21	.07607	13.1461	.09365	10.6783	.11128	8.98598	.12899	7.75254	39
22	.07636	13.0958	.09394	10.6450	.11158	8.96227	.12929	7.73480	38
23	.07665	13.0458	.09423	10.6118	.11187	8.93867	.12958	7.71715	37
24	.07695	12.9962	.09453	10.5789	.11217	8.91520	.12988	7.69957	36
25	.07724	12.9469	.09482	10.5462	.11246	8.89185	.13017	7.68208	35
26	.07753	12.8981	.09511	10.5136	.11276	8.86862	.13047	7.66466	34
27	.07782	12.8496	.09541	10.4813	.11305	8.84551	.13076	7.64732	33
28	.07812	12.8014	.09570	10.4491	.11335	8.82252	.13106	7.63005	32
29	.07841	12.7536	.09600	10.4172	.11364	8.79964	.13136	7.61287	31
30	.07870	12.7062	.09629	10.3854	.11394	8.77689	.13165	7.59575	30
31	.07899	12.6591	.09658	10.3538	.11423	8.75425	.13195	7.57872	29
32	.07929	12.6124	.09688	10.3224	.11452	8.73172	.13224	7.56176	28
33	.07958	12.5660	.09717	10.2913	.11482	8.70931	.13254	7.54487	27
34	.07987	12.5199	.09746	10.2602	.11511	8.68701	.13284	7.52806	26
35	.08017	12.4742	.09776	10.2294	.11541	8.66482	.13313	7.51132	25
36	.08046	12.4288	.09805	10.1988	.11570	8.64275	.13343	7.49465	24
37	.08075	12.3838	.09834	10.1683	.11600	8.62078	.13372	7.47806	23
38	.08104	12.3390	.09864	10.1381	.11629	8.59893	.13402	7.46154	22
39	.08134	12.2946	.09893	10.1080	.11659	8.57718	.13432	7.44509	21
40	.08163	12.2505	.09923	10.0780	.11688	8.55555	.13461	7.42871	20
41	.08192	12.2067	.09952	10.0483	.11718	8.53402	.13491	7.41240	19
42	.08221	12.1632	.09981	10.0187	.11747	8.51259	.13521	7.39616	18
43	.08251	12.1201	.10011	9.98931	.11777	8.49128	.13550	7.37999	17
44	.08280	12.0772	.10040	9.96007	.11806	8.47007	.13580	7.36389	16
45	.08309	12.0346	.10069	9.93101	.11836	8.44896	.13609	7.34786	15
46	.08339	11.9923	.10099	9.90211	.11865	8.42795	.13639	7.33190	14
47	.08368	11.9504	.10128	9.87338	.11895	8.40705	.13669	7.31600	13
48	.08397	11.9087	.10158	9.84482	.11924	8.38625	.13698	7.30018	12
49	.08427	11.8673	.10187	9.81641	.11954	8.36555	.13728	7.28442	11
50	.08456	11.8262	.10216	9.78817	.11983	8.34496	.13758	7.26873	10
51	.08485	11.7853	.10246	9.76009	.12013	8.32446	.13787	7.25310	9
52	.08514	11.7448	.10275	9.73217	.12042	8.30406	.13817	7.23754	8
53	.08544	11.7045	.10305	9.70441	.12072	8.28376	.13846	7.22204	7
54	.08573	11.6645	.10334	9.67680	.12101	8.26355	.13876	7.20661	6
55	.08602	11.6248	.10363	9.64935	.12131	8.24345	.13906	7.19125	5
56	.08632	11.5853	.10393	9.62205	.12160	8.22344	.13935	7.17594	4
57	.08661	11.5461	.10422	9.59490	.12190	8.20352	.13965	7.16071	3
58	.08690	11.5072	.10452	9.56791	.12219	8.18370	.13995	7.14553	2
59	.08720	11.4685	.10481	9.54106	.12249	8.16398	.14024	7.13042	1
60	.08749	11.4301	.10510	9.51436	.12278	8.14435	.14054	7.11537	0
′	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	′
	85°		84°		83°		82°		

′	8°		9°		10°		11°	
	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.
0	.14054	7.11537	.15838	6.31375	.17633	5.67128	.19438	5.14455
1	.14084	7.10038	.15868	6.30189	.17663	5.66165	.19468	5.13658
2	.14113	7.08546	.15898	6.29007	.17693	5.65205	.19498	5.12862
3	.14143	7.07059	.15928	6.27829	.17723	5.64248	.19529	5.12069
4	.14173	7.05579	.15958	6.26655	.17753	5.63295	.19559	5 11279
5	.14202	7.04105	.15988	6.25486	.17783	5.62344	.19589	5 10490
6	.14232	7.02637	.16017	6.24321	.17813	5.61397	.19619	5.09704
7	.14262	7.01174	.16047	6.23160	.17843	5.60452	.19649	5.08921
8	.14291	6.99718	.16077	6.22003	.17873	5.59511	.19680	5.08139
9	.14321	6.98268	.16107	6.20851	.17903	5.58573	19710	5.07360
10	.14351	6.96823	.16137	6.19703	.17933	5.57638	19740	5.06584
11	.14381	6.95385	.16167	6.18559	.17963	5.56706	.19770	5.05809
12	.14410	6.93952	.16196	6.17419	.17993	5.55777	.19801	5.05037
13	.14440	6.92525	.16226	6.16283	.18023	5.54851	.19831	5.04267
14	.14470	6.91104	.16256	6.15151	.18053	5.53927	.19861	5.03499
15	.14499	6.89688	.16286	6.14023	.18083	5.53007	.19891	5.02734
16	.14529	6.88278	.16316	6.12899	.18113	5.52090	.19921	5.01971
17	.14559	6.86874	.16346	6.11779	.18143	5.51176	.19952	5.01210
18	.14588	6.85475	.16376	6.10664	.18173	5.50264	.19982	5.00451
19	.14618	6.84082	.16405	6.09552	.18203	5.49356	.20012	4.99695
20	.14648	6.82694	.16435	6.08444	.18233	5.48451	.20042	4.98940
21	.14678	6.81312	.16465	6.07340	.18263	5.47548	.20073	4.98188
22	.14707	6.79936	.16495	6.06240	.18293	5.46648	.20103	4.97438
23	.14737	6.78564	.16525	6.05143	.18323	5.45751	.20133	4 96690
24	.14767	6.77199	.16555	6.04051	.18353	5.44857	.20164	4 95945
25	.14796	6.75838	.16585	6.02962	.18383	5.43966	.20194	4.95201
26	.14826	6.74483	.16615	6.01878	.18414	5.43077	.20224	4 94460
27	.14856	6.73133	.16645	6.00797	.18444	5.42192	.20254	4.93721
28	.14886	6.71789	.16674	5.99720	.18474	5.41309	.20285	4.92984
29	.14915	6.70450	.16704	5.98646	.18504	5.40429	.20315	4 92249
30	.14945	6.69116	.16734	5.97576	.18534	5.39552	.20345	4.91516
31	.14975	6.67787	.16764	5.96510	.18564	5.38677	.20376	4.90785
32	.15005	6.66463	.16794	5.95448	.18594	5.37805	.20406	4.90056
33	.15034	6.65144	.16824	5.94390	.18624	5.36936	.20436	4.89330
34	.15064	6.63831	.16854	5.93335	.18654	5.36070	.20466	4.83605
35	.15094	6.62523	.16884	5.92283	.18684	5.35206	.20497	4.87882
36	.15124	6.61219	.16914	5.91235	.18714	5.34345	.20527	4.87162
37	.15153	6.59921	.16944	5.90191	.18745	5.33487	.20557	4.86444
38	.15183	6.58627	.16974	5.89151	.18775	5.32631	.20588	4.85727
39	.15213	6.57339	.17004	5.88114	.18805	5.31778	.20618	4.85013
40	.15243	6.56055	.17033	5.87080	.18835	5.30928	.20648	4.84300
41	.15272	6.54777	.17063	5.86051	.18865	5.30080	.20679	4.83590
42	.15302	6.53503	.17093	5.85024	.18895	5.29235	.20709	4.82882
43	.15332	6.52234	.17123	5.84001	.18925	5.28393	.20739	4.82175
44	.15362	6.50970	.17153	5.82982	.18955	5.27553	.20770	4.81471
45	.15391	6.49710	.17183	5.81966	.18986	5.26715	.20800	4.80769
46	.15421	6.48456	.17213	5.80953	.19016	5.25880	.20830	4.80068
47	.15451	6.47206	.17243	5.79944	.19046	5.25048	.20861	4.79370
48	.15481	6.45961	.17273	5.78938	.19076	5.24218	.20891	4.78673
49	.15511	6.44720	.17303	5.77936	.19106	5.23391	.20921	4.77978
50	.15540	6.43484	.17333	5.76937	.19136	5.22566	.20952	4.77286
51	.15570	6.42253	.17363	5.75941	.19166	5.21744	.20982	4.76595
52	.15600	6.41026	.17393	5.74949	.19197	5.20925	.21013	4.75906
53	.15630	6.39804	.17423	5.73960	.19227	5.20107	.21043	4.75219
54	.15660	6.38587	.17453	5.72974	.19257	5.19293	.21073	4.74534
55	.15689	6.37374	.17483	5.71992	.19287	5.18480	.21104	4.73851
56	.15719	6.36165	.17513	5.71013	.19317	5.17671	.21134	4.73170
57	.15749	6.34961	.17543	5.70037	.19347	5.16863	.21164	4.72490
58	.15779	6.33761	.17573	5.69064	.19378	5.16058	.21195	4.71813
59	.15809	6.32566	.17603	5.68094	.19408	5.15256	.21225	4.71137
60	.15838	6.31375	.17633	5.67128	.19438	5.14455	.21256	4.70463
′	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.
	81°		80°		79°		78°	

′	12°		13°		14°		15°		′
	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan	
0	.21256	4·70463	.23087	4·33148	.24933	4·01078	.26795	3·73205	60
1	.21286	4·69791	.23117	4·32573	.24964	4·00582	.26826	3·72771	59
2	.21316	4·69121	.23148	4·32001	.24995	4·00086	.26857	3·72338	58
3	.21347	4·68452	.23179	4·31430	.25026	3·99592	.26888	3·71907	57
4	.21377	4·67786	.23209	4·30860	.25056	3·99099	.26920	3·71476	56
5	.21408	4·67121	.23240	4·30291	.25087	3·98607	.26951	3·71046	55
6	.21438	4·66458	.23271	4·29724	.25118	3·98117	.26982	3·70616	54
7	.21469	4·65797	.23301	4·29159	.25149	3·97627	.27013	3·70188	53
8	.21499	4·65138	.23332	4·28595	.25180	3·97139	.27044	3·69761	52
9	.21529	4·64480	.23363	4·28032	.25211	3·96651	.27076	3·69335	51
10	.21560	4·63825	.23393	4·27471	.25242	3·96165	.27107	3·68909	50
11	.21590	4·63171	.23424	4·26911	.25273	3·95680	.27138	3·68485	49
12	.21621	4·62518	.23455	4·26352	.25304	3·95196	.27169	3·68061	48
13	.21651	4·61868	.23485	4·25795	.25335	3·94713	.27201	3·67638	47
14	.21682	4·61219	.23516	4·25239	.25366	3·94232	.27232	3·67217	46
15	.21712	4·60572	.23547	4·24685	.25397	3·93751	.27263	3·66796	45
16	.21743	4·59927	.23578	4·24132	.25428	3·93271	.27294	3·66376	44
17	.21773	4·59283	.23608	4·23580	.25459	3·92793	.27326	3·65957	43
18	.21804	4·58641	.23639	4·23030	.25490	3·92316	.27357	3·65538	42
19	.21834	4·58001	.23670	4·22481	.25521	3·91839	.27388	3·65121	41
20	.21864	4·57363	.23700	4·21933	.25552	3·91364	.27419	3·64705	40
21	.21895	4·56726	.23731	4·21387	.25583	3·90890	.27451	3·64289	39
22	.21925	4·56091	.23762	4·20842	.25614	3·90417	.27482	3·63874	38
23	.21956	4·55458	.23793	4·20298	.25645	3·89945	.27513	3·63461	37
24	.21986	4·54826	.23823	4·19756	.25676	3·89474	.27545	3·63048	36
25	.22017	4·54196	.23854	4·19215	.25707	3·89004	.27576	3·62636	35
26	.22047	4·53568	.23885	4·18675	.25738	3·88536	.27607	3·62224	34
27	.22078	4·52941	.23916	4·18137	.25769	3·88068	.27638	3·61814	33
28	.22108	4·52316	.23946	4·17600	.25800	3·87601	.27670	3·61405	32
29	.22139	4·51693	.23977	4·17064	.25831	3·87136	.27701	3·60996	31
30	.22169	4·51071	.24008	4·16530	.25862	3·86671	.27732	3·60588	30
31	.22200	4·50451	.24039	4·15997	.25893	3·86208	.27764	3·60181	29
32	.22231	4·49832	.24069	4·15465	.25924	3·85745	.27795	3·59775	28
33	.22261	4·49215	.24100	4·14934	.25955	3·85284	.27826	3·59370	27
34	.22292	4·48600	.24131	4·14405	.25986	3·84824	.27858	3·58966	26
35	.22322	4·47986	.24162	4·13877	.26017	3·84364	.27889	3·58562	25
36	.22353	4·47374	.24193	4·13350	.26048	3·83906	.27920	3·58160	24
37	.22383	4·46764	.24223	4·12825	.26079	3·83449	.27952	3·57758	23
38	.22414	4·46155	.24254	4·12301	.26110	3·82992	.27983	3·57357	22
39	.22444	4·45548	.24285	4·11778	.26141	3·82537	.28015	3·56957	21
40	.22475	4·44942	.24316	4·11256	.26172	3·82083	.28046	3·56557	20
41	.22505	4·44338	.24347	4·10736	.26203	3·81630	.28077	3·56159	19
42	.22536	4·43735	.24377	4·10216	.26235	3·81177	.28109	3·55761	18
43	.22567	4·43134	.24408	4·09699	.26266	3·80726	.28140	3·55364	17
44	.22597	4·42534	.24439	4·09182	.26297	3·80276	.28172	3·54968	16
45	.22628	4·41936	.24470	4·08666	.26328	3·79827	.28203	3·54573	15
46	.22658	4·41340	.24501	4·08152	.26359	3·79378	.28234	3·54179	14
47	.22689	4·40745	.24532	4·07639	.26390	3·78931	.28266	3·53785	13
48	.22719	4·40152	.24562	4·07127	.26421	3·78485	.28297	3·53393	12
49	.22750	4·39560	.24593	4·06616	.26452	3·78040	.28329	3·53001	11
50	.22781	4·38969	.24624	4·06107	.26483	3·77595	.28360	3·52609	10
51	.22811	4·38381	.24655	4·05599	.26515	3·77152	.28391	3·52219	9
52	.22842	4·37793	.24686	4·05092	.26546	3·76709	.28423	3·51829	8
53	.22872	4·37207	.24717	4·04586	.26577	3·76268	.28454	3·51441	7
54	.22903	4·36623	.24747	4·04081	.26608	3·75828	.28486	3·51053	6
55	.22934	4·36040	.24778	4·03578	.26639	3·75388	.28517	3·50666	5
56	.22964	4·35459	.24809	4·03075	.26670	3·74950	.28549	3·50279	4
57	.22995	4·34879	.24840	4·02574	.26701	3·74512	.28580	3·49894	3
58	.23026	4·34300	.24871	4·02074	.26733	3·74075	.28612	3·49509	2
59	.23056	4·33723	.24902	4·01576	.26764	3·73640	.28643	3·49125	1
60	.23087	4·33148	.24933	4·01078	.26795	3·73205	.28675	3·48741	0
′	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	′
	77°		76°		75°		74°		

′	16°		17°		18°		19°		′
	Tan.	**Co-tan.**	**Tan.**	**Co-tan.**	**Tan.**	**Co-tan.**	**Tan.**	**Co-tan.**	
0	.28675	3.48741	.30573	3.27085	.32492	3.07768	.34433	2.90421	60
1	.28706	3.48359	.30605	3.26745	.32524	3.07464	.34465	2.90147	59
2	.28738	3.47977	.30637	3.26406	.32556	3.07160	.34498	2.89873	58
3	.28769	3.47596	.30669	3.26067	.32588	3.06857	.34530	2.89600	57
4	.28800	3.47216	.30700	3.25729	.32621	3.06554	.34563	2.89327	56
5	.28832	3.46837	.30732	3.25392	.32653	3.06252	.34596	2.89055	55
6	.28864	3.46458	.30764	3.25055	.32685	3.05950	.34628	2.88783	54
7	.28895	3.46080	.30796	3.24719	.32717	3.05649	.34661	2.88511	53
8	.28927	3.45703	.30828	3.24383	.32749	3.05349	.34693	2.88240	52
9	.28958	3.45327	.30860	3.24049	.32782	3.05049	.34726	2.87970	51
10	.28990	3.44951	.30891	3.23714	.32814	3.04749	.34758	2.87700	50
11	.29021	3.44576	.30923	3.23381	.32846	3.04450	.34791	2.87430	49
12	.29053	3.44202	.30955	3.23048	.32878	3.04152	.34824	2.87161	48
13	.29084	3.43829	.30987	3.22715	.32911	3.03854	.34856	2.86892	47
14	.29116	3.43456	.31019	3.22384	.32943	3.03556	.34889	2.86624	46
15	.29147	3.43084	.31051	3.22053	.32975	3.03260	.34922	2.86356	45
16	.29179	3.42713	.31083	3.21722	.33007	3.02963	.34954	2.86089	44
17	.29210	3.42343	.31115	3.21392	.33040	3.02667	.34987	2.85822	43
18	.29242	3.41973	.31147	3.21063	.33072	3.02372	.35019	2.85555	42
19	.29274	3.41604	.31178	3.20734	.33104	3.02077	.35052	2.85289	41
20	.29305	3.41236	.31210	3.20406	.33136	3.01783	.35085	2.85023	40
21	.29337	3.40869	.31242	3.20079	.33160	3.01489	.35117	2.84758	39
22	.29368	3.40502	.31274	3.19752	.33201	3.01196	.35150	2.84494	38
23	.29400	3.40136	.31306	3.19426	.33233	3.00903	.35183	2.84229	37
24	.29432	3.39771	.31338	3.19100	.33266	3.00611	.35216	2.83965	36
25	.29463	3.39406	.31370	3.18775	.33298	3.00319	.35248	2.83702	35
26	.29495	3.39042	.31402	3.18451	.33330	3.00028	.35281	2.83439	34
27	.29526	3.38679	.31434	3.18127	.33363	2.99738	.35314	2.83176	33
28	.29558	3.38317	.31466	3.17804	.33395	2.99447	.35346	2.82914	32
29	.29590	3.37955	.31498	3.17481	.33427	2.99158	.35379	2.82653	31
30	.29621	3.37594	.31530	3.17159	.33460	2.98868	.35412	2.82391	30
31	.29653	3.37234	.31562	3.16838	.33492	2.98580	.35445	2.82130	29
32	.29685	3.36875	.31594	3.16517	.33524	2.98292	.35477	2.81870	28
33	.29716	3.36516	.31626	3.16197	.33557	2.98004	.35510	2.81610	27
34	.29748	3.36158	.31658	3.15877	.33589	2.97717	.35543	2.81350	26
35	.29780	3.35800	.31690	3.15558	.33621	2.97430	.35576	2.81091	25
36	.29811	3.35443	.31722	3.15240	.33654	2.97144	.35608	2.80833	24
37	.29843	3.35087	.31754	3.14922	.33686	2.96858	.35641	2.80574	23
38	.29875	3.34732	.31786	3.14605	.33718	2.96573	.35674	2.80316	22
39	.29906	3.34377	.31818	3.14288	.33751	2.96288	.35707	2.80059	21
40	.29938	3.34023	.31850	3.13972	.33783	2.96004	.35740	2.79802	20
41	.29970	3.33670	.31882	3.13656	.33816	2.95721	.35772	2.79545	19
42	.30001	3.33317	.31914	3.13341	.33848	2.95437	.35805	2.79289	18
43	.30033	3.32965	.31946	3.13027	.33881	2.95155	.35838	2.79033	17
44	.30065	3.32614	.31978	3.12713	.33913	2.94872	.35871	2.78778	16
45	.30097	3.32264	.32010	3.12400	.33945	2.94590	.35904	2.78523	15
46	.30128	3.31914	.32042	3.12087	.33978	2.94309	.35937	2.78269	14
47	.30160	3.31565	.32074	3.11775	.34010	2.94028	.35969	2.78014	13
48	.30192	3.31216	.32106	3.11464	.34043	2.93748	.36002	2.77761	12
49	.30224	3.30868	.32139	3.11153	.34075	2.93468	.36035	2.77507	11
50	.30255	3.30521	.32171	3.10842	.34108	2.93189	.36068	2.77254	10
51	.30287	3.30174	.32203	3.10532	.34140	2.92910	.36101	2.77002	9
52	.30319	3.29829	.32235	3.10223	.34173	2.92632	.36134	2.76750	8
53	.30351	3.29483	.32267	3.09914	.34205	2.92354	.36167	2.76498	7
54	.30382	3.29139	.32299	3.09606	.34238	2.92076	.36199	2.76247	6
55	.30414	3.28795	.32331	3.09298	.34270	2.91799	.36232	2.75996	5
56	.30446	3.28452	.32363	3.08991	.34303	2.91523	.36265	2.75746	4
57	.30478	3.28109	.32396	3.08685	.34335	2.91246	.36298	2.75496	3
58	.30509	3.27767	.32428	3.08379	.34368	2.90971	.36331	2.75246	2
59	.30541	3.27426	.32460	3.08073	.34400	2.90696	.36364	2.74997	1
60	.30573	3.27085	.32492	3.07768	.34433	2.90421	.36397	2.74748	0
′	**Co-tan.**	**Tan.**	**Co-tan.**	**Tan.**	**Co-tan.**	**Tan.**	**Co-tan.**	**Tan.**	′
	73°		72°		71°		70°		

	20°		21°		22°		23°		
′	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	′
0	.36397	2.74748	.38386	2.60509	.40403	2.47509	.42447	2.35585	60
1	.36430	2.74499	.38420	2.60283	.40436	2.47302	.42482	2.35395	59
2	.36463	2.74251	.38453	2.60057	.40470	2.47095	.42516	2.35205	58
3	.36496	2.74004	.38487	2.59831	.40504	2.46888	.42551	2.35015	57
4	.36529	2.73756	.38520	2.59606	.40538	2.46682	.42585	2.34825	56
5	.36562	2.73509	.38553	2.59381	.40572	2.46476	.42619	2.34636	55
6	.36595	2.73263	.38587	2.59156	.40606	2.46270	.42654	2.34447	54
7	.36628	2.73017	.38620	2.58932	.40640	2.46065	.42688	2.34258	53
8	.36661	2.72771	.38654	2.58708	.40674	2.45860	.42722	2.34069	52
9	.36694	2.72526	.38687	2.58484	.40707	2.45655	.42757	2.33881	51
10	.36727	2.72281	.38721	2.58261	.40741	2.45451	.42791	2.33693	50
11	.36760	2.72036	.38754	2.58038	.40775	2.45246	.42826	2.33505	49
12	.36793	2.71792	.38787	2.57815	.40809	2.45043	.42860	2.33317	48
13	.36826	2.71548	.38821	2.57593	.40843	2.44839	.42894	2.33130	47
14	.36859	2.71305	.38854	2.57371	.40877	2.44636	.42929	2.32943	46
15	.36892	2.71062	.38888	2.57150	.40911	2.44433	.42963	2.32756	45
16	.36925	2.70819	.38921	2.56928	.40945	2.44230	.42998	2.32570	44
17	.36958	2.70577	.38955	2.56707	.40979	2.44027	.43032	2.32383	43
18	.36991	2.70335	.38988	2.56487	.41013	2.43825	.43067	2.32197	42
19	.37024	2.70094	.39022	2.56266	.41047	2.43623	.43101	2.32012	41
20	.37057	2.69853	.39055	2.56046	.41081	2.43422	.43136	2.31826	40
21	.37090	2.69612	.39089	2.55827	.41115	2.43220	.43170	2.31641	39
22	.37124	2.69371	.39122	2.55608	.41149	2.43019	.43205	2.31456	38
23	.37157	2.69131	.39156	2.55389	.41183	2.42819	.43239	2.31271	37
24	.37190	2.68892	.39190	2.55170	.41217	2.42618	.43274	2.31086	36
25	.37223	2.68653	.39223	2.54952	.41251	2.42418	.43308	2.30902	35
26	.37256	2.68414	.39257	2.54734	.41285	2.42218	.43343	2.30718	34
27	.37289	2.68175	.39290	2.54516	.41319	2.42019	.43378	2.30534	33
28	.37322	2.67937	.39324	2.54299	.41353	2.41819	.43412	2.30351	32
29	.37355	2.67700	.39357	2.54082	.41387	2.41620	.43447	2.30167	31
30	.37388	2.67462	.39391	2.53865	.41421	2.41421	.43481	2.29984	30
31	.37422	2.67225	.39425	2.53648	.41455	2.41223	.43516	2.29801	29
32	.37455	2.66989	.39458	2.53432	.41490	2.41025	.43550	2.29619	28
33	.37488	2.66752	.39492	2.53217	.41524	2.40827	.43585	2.29437	27
34	.37521	2.66516	.39526	2.53001	.41558	2.40629	.43620	2.29254	26
35	.37554	2.66281	.39559	2.52786	.41592	2.40432	.43654	2.29073	25
36	.37588	2.66046	.39593	2.52571	.41626	2.40235	.43689	2.28891	24
37	.37621	2.65811	.39626	2.52357	.41660	2.40038	.43724	2.28710	23
38	.37654	2.65576	.39660	2.52142	.41694	2.39841	.43758	2.28528	22
39	.37687	2.65342	.39694	2.51929	.41728	2.39645	.43793	2.28348	21
40	.37720	2.65109	.39727	2.51715	.41763	2.39449	.43828	2.28167	20
41	.37754	2.64875	.39761	2.51502	.41797	2.39253	.43862	2.27987	19
42	.37787	2.64642	.39795	2.51289	.41831	2.39058	.43897	2.27806	18
43	.37820	2.64410	.39829	2.51076	.41865	2.38862	.43932	2.27626	17
44	.37853	2.64177	.39862	2.50864	.41899	2.38668	.43966	2.27447	16
45	.37887	2.63945	.39896	2.50652	.41933	2.38473	.44001	2.27267	15
46	.37920	2.63714	.39930	2.50440	.41968	2.38279	.44036	2.27088	14
47	.37953	2.63483	.39963	2.50229	.42002	2.38084	.44071	2.26909	13
48	.37986	2.63252	.39997	2.50018	.42036	2.37891	.44105	2.26730	12
49	.38020	2.63021	.40031	2.49807	.42070	2.37697	.44140	2.26552	11
50	.38053	2.62791	.40065	2.49597	.42105	2.37504	.44175	2.26374	10
51	.38086	2.62561	.40098	2.49386	.42139	2.37311	.44210	2.26196	9
52	.38120	2.62332	.40132	2.49177	.42173	2.37118	.44244	2.26018	8
53	.38153	2.62103	.40166	2.48967	.42207	2.36925	.44279	2.25840	7
54	.38186	2.61874	.40200	2.48758	.42242	2.36733	.44314	2.25663	6
55	.38220	2.61646	.40234	2.48549	.42276	2.36541	.44349	2.25486	5
56	.38253	2.61418	.40267	2.48340	.42310	2.36349	.44384	2.25309	4
57	.38286	2.61190	.40301	2.48132	.42345	2.36158	.44418	2.25132	3
58	.38320	2.60963	.40335	2.47924	.42379	2.35967	.44453	2.24956	2
59	.38353	2.60736	.40369	2.47716	.42413	2.35776	.44488	2.24780	1
60	.38386	2.60509	.40403	2.47509	.42447	2.35585	.44523	2.24604	0
′	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	′
	69°		68°		67°		66°		

	24°		25°		26°		27°		
′	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.	
0	.44523	2.24604	.46631	2.14451	.48773	2.05030	.50953	1.96261	60
1	.44558	2.24428	.46666	2.14288	.48809	2.04879	.50989	1.96120	59
2	.44593	2.24252	.46702	2.14125	.48845	2.04728	.51026	1.95979	58
3	.44627	2.24077	.46737	2.13963	.48881	2.04577	.51063	1.95838	57
4	.44662	2.23902	.46772	2.13801	.48917	2.04426	.51099	1.95698	56
5	.44697	2.23727	.46808	2.13639	.48953	2.04276	.51136	1.95557	55
6	.44732	2.23553	.46843	2.13477	.48989	2.04125	.51173	1.95417	54
7	.44767	2.23378	.46879	2.13316	.49026	2.03975	.51209	1.95277	53
8	.44802	2.23204	.46914	2.13154	.49062	2.03825	.51246	1.95137	52
9	.44837	2.23030	.46950	2.12993	.49098	2.03675	.51283	1.94997	51
10	.44872	2.22857	.46985	2.12832	.49134	2.03526	.51319	1.94858	50
11	.44907	2.22683	.47021	2.12671	.49170	2.03376	.51356	1.94718	49
12	.44942	2.22510	.47056	2.12511	.49206	2.03227	.51393	1.94579	48
13	.44977	2.22337	.47092	2.12350	.49242	2.03078	.51430	1.94440	47
14	.45012	2.22164	.47128	2.12190	.49278	2.02929	.51467	1.94301	46
15	.45047	2.21992	.47163	2.12030	.49315	2.02780	.51503	1.94162	45
16	.45082	2.21819	.47199	2.11871	.49351	2.02631	.51540	1.94023	44
17	.45117	2.21647	.47234	2.11711	.49387	2.02483	.51577	1.93885	43
18	.45152	2.21475	.47270	2.11552	.49423	2.02335	.51614	1.93746	42
19	.45187	2.21304	.47305	2.11392	.49459	2.02187	.51651	1.93608	41
20	.45222	2.21132	.47341	2.11233	.49495	2.02039	.51688	1.93470	40
21	.45257	2.20961	.47377	2.11075	.49532	2.01891	.51724	1.93332	39
22	.45292	2.20790	.47412	2.10916	.49568	2.01743	.51761	1.93195	38
23	.45327	2.20619	.47448	2.10758	.40604	2.01596	.51798	1.93057	37
24	.45362	2.20449	.47483	2.10600	.49640	2.01449	.51835	1.92920	36
25	.45397	2.20278	.47519	2.10442	.49677	2.01302	.51872	1.92782	35
26	.45432	2.20108	.47555	2.10284	.49713	2.01155	.51909	1.92645	34
27	.45467	2.19938	.47590	2.10126	.49749	2.01008	.51946	1.92508	33
28	.45502	2.19769	.47626	2.09969	.49786	2.00862	.51983	1.92371	32
29	.45537	2.19599	.47662	2.09811	.49822	2.00715	.52020	1.92235	31
30	.45573	2.19430	.47698	2.09654	.49858	2.00569	.52057	1.92098	30
31	.45608	2.19261	.47733	2.09498	.49894	2.00423	.52094	1.91962	29
32	.45643	2.19092	.47769	2.09341	.49931	2.00277	.52131	1.91826	28
33	.45678	2.18923	.47805	2.09184	.49967	2.00131	.52168	1.91690	27
34	.45713	2.18755	.47840	2.09028	.50004	1.99986	.52205	1.91554	26
35	.45748	2.18587	.47876	2.08872	.50040	1.99841	.52242	1.91418	25
36	.45784	2.18419	.47912	2.08716	.50076	1.99695	.52279	1.91282	24
37	.45819	2.18251	.47948	2.08560	.50113	1.99550	.52316	1.91147	23
38	.45854	2.18084	.47984	2.08405	.50149	1.99406	.52353	1.91012	22
39	.45889	2.17916	.48019	2.08250	.50185	1.99261	.52390	1.90876	21
40	.45924	2.17749	.48055	2.08094	.50222	1.99116	.52427	1.90741	20
41	.45960	2.17582	.48091	2.07939	.50258	1.98972	.52464	1.90607	19
42	.45995	2.17416	.48127	2.07785	.50295	1.98828	.52501	1.90472	18
43	.46030	2.17249	.48163	2.07630	.50331	1.98684	.52538	1.90337	17
44	.46065	2.17083	.48198	2.07476	.50368	1.98540	.52575	1.90203	16
45	.46101	2.16917	.48234	2.07321	.50404	1.98396	.52613	1.90069	15
46	.46136	2.16751	.48270	2.07167	.50441	1.98253	.52650	1.89935	14
47	.46171	2.16585	.48306	2.07014	.50477	1.98110	.52687	1.89801	13
48	.46206	2.16420	.48342	2.06860	.50514	1.97966	.52724	1.89667	12
49	.46242	2.16255	.48378	2.06706	.50550	1.97823	.52761	1.89533	11
50	.46277	2.16090	.48414	2.06553	.50587	1.97680	.52798	1.89400	10
51	.46312	2.15925	.48450	2.06400	.50623	1.97538	.52836	1.89266	9
52	.46348	2.15760	.48486	2.06247	.50660	1.97395	.52873	1.89133	8
53	.46383	2.15596	.48521	2.06094	.50696	1.97253	.52910	1.89000	7
54	.46418	2.15432	.48557	2.05942	.50733	1.97111	.52947	1.88867	6
55	.46454	2.15268	.48593	2.05790	.50769	1.96969	.52984	1.88734	5
56	.46489	2.15104	.48629	2.05637	.50806	1.96827	.53022	1.88602	4
57	.46525	2.14940	.48665	2.05485	.50843	1.96685	.53059	1.88469	3
58	.46560	2.14777	.48701	2.05333	.50879	1.96544	.53096	1.88337	2
59	.46595	2.14614	.48737	2.05182	.50916	1.96402	.53134	1.88205	1
60	.46631	2.14451	.48773	2.05030	.50953	1.96261	.53171	1.88073	0
′	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	′
	65°		64°		63°		62°		

	28°		29°		30°		31°		
	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.	
0	.53171	1.88073	.55431	1.80405	.57735	1.73205	.60086	1.66428	60
1	.53208	1.87941	.55469	1.80281	.57774	1.73089	.60126	1.66318	59
2	.53246	1.87809	.55507	1.80158	.57813	1.72973	.60165	1.66209	58
3	.53283	1.87677	.55545	1.80034	.57851	1.72857	.60205	1.66099	57
4	.53320	1.87546	.55583	1.79911	.57890	1.72741	.60245	1.65990	56
5	.53358	1.87415	.55621	1.79788	.57929	1.72625	.60284	1.65881	55
6	.53395	1.87283	.55659	1.79665	.57968	1.72509	.60324	1.65772	54
7	.53432	1.87152	.55697	1.79542	.58007	1.72393	.60364	1.65663	53
8	.53470	1.87021	.55736	1.79419	.58046	1.72278	.60403	1.65534	52
9	.53507	1.86891	.55774	1.79296	.58085	1.72163	.60443	1.65445	51
10	.53545	1.86760	.55812	1.79174	.58124	1.72047	.60483	1.65337	50
11	.53582	1.86630	.55850	1.79051	.58162	1.71932	.60522	1.65228	49
12	.53620	1.86499	.55888	1.78929	.58201	1.71817	.60562	1.65120	48
13	.53657	1.86369	.55926	1.78807	.58240	1.71702	.60602	1.65011	47
14	.53694	1.86239	.55964	1.78685	.58279	1.71588	.60642	1.64903	46
15	.53732	1.86109	.56003	1.78563	.58318	1.71473	.60681	1.64795	45
16	.53769	1.85979	.56041	1.78441	.58357	1.71358	.60721	1.64687	44
17	.53807	1.85850	.56079	1.78319	.58396	1.71244	.60761	1.64579	43
18	.53844	1.85720	.56117	1.78198	.58435	1.71129	.60801	1.64471	42
19	.53882	1.85591	.56156	1.78077	.58474	1.71015	.60841	1.64363	41
20	.53920	1.85462	.56194	1.77955	.58513	1.70901	.60881	1.64256	40
21	.53957	1.85333	.56232	1.77834	.58552	1.70787	.60921	1.64148	39
22	.53995	1.85204	.56270	1.77713	.58591	1.70673	.60960	1.64041	38
23	.54032	1.85075	.56309	1.77592	.58631	1.70560	.61000	1.63934	37
24	.54070	1.84946	.56347	1.77471	.58670	1.70446	.61040	1.63826	36
25	.54107	1.84818	.56385	1.77351	.58709	1.70332	.61080	1.63719	35
26	.54145	1.84689	.56424	1.77230	.58748	1.70219	.61120	1.63612	34
27	.54183	1.84561	.56462	1.77110	.58787	1.70106	.61160	1.63505	33
28	.54220	1.84433	.56500	1.76990	.58826	1.69992	.61200	1.63398	32
29	.54258	1.84305	.56539	1.76869	.58865	1.69879	.61240	1.63292	31
30	.54296	1.84177	.56577	1.76749	.58904	1.69766	.61280	1.63185	30
31	.54333	1.84049	.56616	1.76630	.58944	1.69653	.61320	1.63079	29
32	.54371	1.83922	.56654	1.76510	.58983	1.69541	.61360	1.62972	28
33	.54409	1.83794	.56693	1.76390	.59022	1.69428	.61400	1.62866	27
34	.54446	1.83667	.56731	1.76271	.59061	1.69316	.61440	1.62760	26
35	.54484	1.83540	.56769	1.76151	.59101	1.69203	.61480	1.62654	25
36	.54522	1.83413	.56808	1·76032	.59140	1.69091	.61520	1.62548	24
37	.54560	1.83286	.56846	1.75913	.59179	1.68979	.61561	1.62442	23
38	.54597	1.83159	.56885	1.75794	.59218	1.68866	.61601	1.62336	22
39	.54635	1.83033	.56923	1.75675	.59258	1.68754	.61641	1.62230	21
40	.54673	1.82906	.56962	1.75556	.59297	1.68643	.61681	1.62125	20
41	.54711	1.82780	.57000	1.75437	.59336	1.68531	.61721	1.62019	19
42	.54748	1.82654	.57030	1.75319	.59376	1.68419	.61761	1.61914	18
43	.54786	1.82528	.57078	1.75200	.59415	1.68308	.61801	1.61808	17
44	.54824	1.82402	.57116	1.75082	.59454	1.68196	.61842	1.61703	16
45	.54862	1.82276	.57155	1.74964	.59494	1.68085	.61882	1.61598	15
46	.54900	1.82150	.57193	1.74846	.59533	1.67974	.61922	1.61493	14
47	.54938	1.82025	.57232	1.74728	.59573	1.67863	.61962	1.61388	13
48	.54975	1.81899	.57271	1.74610	.59612	1.67752	.62003	1.61283	12
49	.55013	1.81774	.57309	1.74492	.59651	1.67641	.62043	1.61179	11
50	.55051	1.81649	.57348	1.74375	.59691	1.67530	.62083	1.61074	10
51	.55089	1.81524	.57386	1.74257	.59730	1.67419	.62124	1.60970	9
52	.55127	1.81399	.57425	1.74140	.59770	1.67309	.62164	1.60865	8
53	.55165	1.81274	.57464	1.74022	.59809	1.67198	.62204	1.60761	7
54	.55203	1.81150	.57503	1.73905	.59849	1.67088	.62245	1.60657	6
55	.55241	1.81025	.57541	1.73788	.59888	1.66978	.62285	1.60553	5
56	.55279	1.80901	.57580	1.73671	.59928	1.66867	.62325	1.60449	4
57	.55317	1.80777	.57619	1.73555	.59967	1.66757	.62366	1.60345	3
58	.55355	1.80653	.57657	1.73438	.60007	1.66647	.62406	1.60241	2
59	.55393	1.80529	.57696	1.73321	.60046	1.66538	.62446	1.60137	1
60	.55431	1.80405	.57735	1.73205	.60086	1.66428	.62487	1.60033	0
	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	
	61°		60°		59°		58°		

	32°		33°		34°		35°		
′	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	′
0	.62487	1.60033	.64941	1.53986	.67451	1.48256	.70021	1.42815	60
1	.62527	1.59930	.64982	1.53888	.67493	1.48163	.70064	1.42726	59
2	.62568	1.59826	.65023	1.53791	.67536	1.48070	.70107	1.42638	58
3	.62608	1.59723	.65065	1.53693	.67578	1.47977	.70151	1.42550	57
4	.62649	1.59620	.65106	1.53595	.67620	1.47885	.70194	1.42462	56
5	.62689	1.59517	.65148	1.53497	.67663	1.47792	.70238	1.42374	55
6	.62730	1.59414	.65189	1.53400	.67705	1.47699	.70281	1.42286	54
7	.62770	1.59311	.65231	1.53302	.67748	1.47607	.70325	1.42198	53
8	.62811	1.59208	.65272	1.53205	.67790	1.47514	.70368	1.42110	52
9	.62852	1.59105	.65314	1.53107	.67832	1.47422	.70412	1.42022	51
10	.62892	1.59002	.65355	1.53010	.67875	1.47330	.70455	1.41934	50
11	.62933	1.58900	.65397	1.52913	.67917	1.47238	.70499	1.41847	49
12	.62973	1.58797	.65438	1.52816	.67960	1.47146	.70542	1.41759	48
13	.63014	1.58695	.65480	1.52719	.68002	1.47053	.70586	1.41672	47
14	.63055	1.58593	.65521	1.52622	.68045	1.46962	.70629	1.41584	46
15	.63095	1.58490	.65563	1.52525	.68088	1.46870	.70673	1.41497	45
16	.63136	1.58388	.65604	1.52429	.68130	1.46778	.70717	1.41409	44
17	.63177	1.58286	.65646	1.52332	.68173	1.46686	.70760	1.41322	43
18	.63217	1.58184	.65688	1.52235	.68215	1.46595	.70804	1.41235	42
19	.63258	1.58083	.65729	1.52139	.68258	1.46503	.70848	1.41148	41
20	.63299	1.57981	.65771	1.52043	.68301	1.46411	.70891	1.41061	40
21	.63340	1.57879	.65813	1.51946	.68343	1.46320	.70935	1.40974	39
22	.63380	1.57778	.65854	1.51850	.68386	1.46229	.70979	1.40887	38
23	.63421	1.57676	.65896	1.51754	.68429	1.46137	.71023	1.40800	37
24	.63462	1.57575	.65938	1.51658	.68471	1.46046	.71066	1.40714	36
25	.63503	1.57474	.65980	1.51562	.68514	1.45955	.71110	1.40627	35
26	.63544	1.57372	.66021	1.51466	.68557	1.45864	.71154	1.40540	34
27	.63584	1.57271	.66063	1.51370	.68600	1.45773	.71198	1.40454	33
28	.63625	1.57170	.66105	1.51275	.68642	1.45682	.71242	1.40367	32
29	.63666	1.57069	.66147	1.51179	.68685	1.45592	.71285	1.40281	31
30	.63707	1.56969	.66189	1.51084	.68728	1.45501	.71329	1.40195	30
31	.63748	1.56868	.66230	1.50988	.68771	1.45410	.71373	1.40109	29
32	.63789	1.56767	.66272	1.50893	.68814	1.45320	.71417	1.40022	28
33	.63830	1.56667	.66314	1.50797	.68857	1.45229	.71461	1.39936	27
34	.63871	1.56566	.66356	1.50702	.68900	1.45139	.71505	1.39850	26
35	.63912	1.56466	.66398	1.50607	.68942	1.45049	.71549	1.39764	25
36	.63953	1.56366	.66440	1.50512	.68985	1.44958	.71593	1.39679	24
37	.63994	1.56265	.66482	1.50417	.69028	1.44868	.71637	1.39593	23
38	.64035	1.56165	.66524	1.50322	.69071	1.44778	.71681	1.39507	22
39	.64076	1.56065	.66566	1.50228	.69114	1.44688	.71725	1.39421	21
40	.64117	1.55966	.66608	1.50133	.69157	1.44598	.71769	1.39336	20
41	.64158	1.55866	.66650	1.50038	.69200	1.44508	.71813	1.39250	19
42	.64199	1.55766	.66692	1.49944	.69243	1.44418	.71857	1.39165	18
43	.64240	1.55666	.66734	1.49849	.69286	1.44329	.71901	1.39079	17
44	.64281	1.55567	.66776	1.49755	.69329	1.44239	.71946	1.38994	16
45	.64322	1.55467	.66818	1.49661	.69372	1.44149	.71990	1.38909	15
46	.64363	1.55368	.66860	1.49566	.69416	1.44060	.72034	1.38824	14
47	.64404	1.55269	.66902	1.49472	.69459	1.43970	.72078	1.38738	13
48	.64446	1.55170	.66944	1.49378	.69502	1.43881	.72122	1.38653	12
49	.64487	1.55071	.66986	1.49284	.69545	1.43792	.72166	1.38568	11
50	.64528	1.54972	.67028	1.49190	.69588	1.43703	.72211	1.38484	10
51	.64569	1.54873	.67071	1.49097	.69631	1.43614	.72255	1.38399	9
52	.64610	1.54774	.67113	1.49003	.69675	1.43525	.72299	1.38314	8
53	.64652	1.54675	.67155	1.48909	.69718	1.43436	.72344	1.38229	7
54	.64693	1.54576	.67197	1.48816	.69761	1.43347	.72388	1.38145	6
55	.64734	1.54478	.67239	1.48722	.69804	1.43258	.72432	1.38060	5
56	.64775	1.54379	.67282	1.48629	.69847	1.43169	.72477	1.37976	4
57	.64817	1.54281	.67324	1.48536	.69891	1.43080	.72521	1.37891	3
58	.64858	1.54183	.67366	1.48442	.69934	1.42992	.72565	1.37807	2
59	.64899	1.54085	.67409	1.48349	.69977	1.42903	.72610	1.37722	1
60	.64941	1.53986	.67451	1.48256	.70021	1.42815	.72654	1.37638	0
′	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	′
	57°		56°		55°		54°		

	36°		37°		38°		39°		
'	**Tan.**	**Co-tan.**	**Tan.**	**Co-tan.**	**Tan.**	**Co-tan.**	**Tan.**	**Co-tan.**	'
0	.72654	1.37638	.75355	1.32704	.78129	1.27994	.80978	1.23490	60
1	.72699	1.37554	.75401	1.32624	.78175	1.27917	.81027	1.23416	59
2	.72743	1.37470	.75447	1.32544	.78222	1.27841	.81075	1.23343	58
3	.72788	1.37386	.75492	1.32464	.78269	1.27764	.81123	1.23270	57
4	.72832	1.37302	.75538	1.32384	.78316	1.27688	.81171	1.23196	56
5	.72877	1.37218	.75584	1.32304	.78363	1.27611	.81220	1.23123	55
6	.72921	1.37134	.75629	1.32224	.78410	1.27535	.81268	1.23050	54
7	.72966	1.37050	.75675	1.32144	.78457	1.27458	.81316	1.22977	53
8	.73010	1.36967	.75721	1.32064	.78504	1.27382	.81364	1.22904	52
9	.73055	1.36883	.75767	1.31984	.78551	1.27306	.81413	1.22831	51
10	.73100	1.36800	75812	1.31904	.78598	1.27230	.81461	1.22758	50
11	.73144	1.36716	75858	1.31825	.78645	1.27153	.81510	1.22685	49
12	.73189	1.36633	.75904	1.31745	.78692	1.27077	.81558	1.22612	48
13	.73234	1.36549	.75950	1.31666	.78739	1.27001	.81606	1.22539	47
14	.73278	1.36466	.75996	1.31586	.78786	1.26925	.81655	1.22467	46
15	.73323	1.36383	.76042	1.31507	.78834	1.26849	.81703	1.22394	45
16	.73368	1.36300	.76088	1.31427	.78881	1.26774	.81752	1.22321	44
17	.73413	1.36217	.76134	1.31348	.78928	1.26698	.81800	1.22249	43
18	.73457	1.36133	.76180	1.31269	.78975	1.26622	.81849	1.22176	42
19	.73502	1.36051	.76226	1.31190	.79022	1.26546	.81898	1.22104	41
20	.73547	1.35968	.76272	1.31110	.79070	1.26471	.81946	1.22031	40
21	.73592	1.35885	.76318	1.31031	.79117	1.26395	.81995	1.21959	39
22	.73637	1.35802	.76364	1.30952	.79164	1.26319	.82044	1.21886	38
23	.73681	1.35719	.76410	1.30873	.79212	1.26244	.82092	1.21814	37
24	.73726	1.35637	.76456	1.30795	.79259	1.26169	.82141	1.21742	36
25	.73771	1.35554	.76502	1.30716	.79306	1.26093	.82190	1.21670	35
26	.73816	1.35472	.76548	1.30637	.79354	1.26018	.82238	1.21598	34
27	.73861	1.35389	.76594	1.30558	.79401	1.25943	.82287	1.21526	33
28	.73906	1.35307	.76640	1.30480	.79449	1.25867	.82336	1.21454	32
29	.73951	1.35224	.76686	1.30401	.79496	1.25792	.82385	1.21382	31
30	.73996	1.35142	.76733	1.30323	.79544	1.25717	.82434	1.21310	30
31	.74041	1.35060	.76779	1.30244	.79591	1.25642	.82483	1.21238	29
32	.74086	1.34978	.76825	1.30166	.79639	1.25567	.82531	1.21166	28
33	.74131	1.34896	.76871	1.30087	.79686	1.25492	.82580	1.21094	27
34	.74176	1.34814	.76918	1.30009	.79734	1.25417	.82629	1.21023	26
35	.74221	1.34732	.76964	1.29931	.79781	1.25343	.82678	1.20951	25
36	.74267	1.34650	.77010	1.29853	.79829	1.25268	.82727	1.20879	24
37	.74312	1.34568	.77057	1.29775	.79877	1.25193	.82776	1.20808	23
38	.74357	1.34487	.77103	1.29696	.79924	1.25118	.82825	1.20736	22
39	.74402	1.34405	.77149	1.29618	.79972	1.25044	.82874	1.20665	21
40	.74447	1.34323	.77196	1.29541	.80020	1.24969	.82923	1.20593	20
41	.74492	1.34242	.77242	1.29463	.80067	1.24895	.82972	1.20522	19
42	.74538	1.34160	.77289	1.29385	.80115	1.24820	.83022	1.20451	18
43	.74583	1.34079	.77335	1.29307	.80163	1.24746	.83071	1.20379	17
44	.74628	1.33998	.77382	1.29229	.80211	1.24672	.83120	1.20308	16
45	.74674	1.33916	.77428	1.29152	.80258	1.24597	.83169	1.20237	15
46	.74719	1.33835	.77475	1.29074	.80306	1.24523	.83218	1.20166	14
47	.74764	1.33754	.77521	1.28997	.80354	1.24449	.83268	1.20095	13
48	.74810	1.33673	.77568	1.28919	.80402	1.24375	.83317	1.20024	12
49	.74855	1.33592	.77615	1.28842	.80450	1.24301	.83366	1.19953	11
50	.74900	1.33511	.77661	1.28764	.80498	1.24227	.83415	1.19882	10
51	.74046	1.33430	.77708	1.28687	.80546	1.24153	.83465	1.19811	9
52	.74091	1.33349	.77754	1.28610	.80594	1.24079	.83514	1.19740	8
53	.75037	1.33268	.77801	1.28533	.80642	1.24005	.83564	1.19669	7
54	.75082	1.33187	.77848	1.28456	.80690	1.23931	.83613	1.19599	6
55	.75128	1.33107	.77895	1.28379	.80738	1.23858	.83662	1.19528	5
56	.75173	1.33026	.77941	1.28302	.80786	1.23784	.83712	1.19457	4
57	.75219	1.32946	.77988	1.28225	.80834	1.23710	.83761	1.19387	3
58	.75264	1.32865	.78035	1.28148	.80882	1.23637	.83811	1.19316	2
59	.75310	1.32785	.78082	1.28071	.80930	1.23563	.83860	1.19246	1
60	.75355	1.32704	.78129	1.27994	.80978	1.23490	.83910	1.19175	0
'	**Co-tan.**	**Tan.**	**Co-tan.**	**Tan.**	**Co-tan.**	**Tan.**	**Co-tan.**	**Tan.**	'
	53°		52°		51°		50°		

	40°		41°		42°		43°		
′	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.	′
0	.83910	1.19175	.86929	1.15037	.90040	1.11061	.93252	1.07237	60
1	.83960	1.19105	.86980	1.14969	.90093	1.10996	.93306	1.07174	59
2	.84009	1.19035	.87031	1.14902	.90146	1.10931	.93360	1.07112	58
3	.84059	1.18964	.87082	1.14834	.90199	1.10867	.93415	1.07049	57
4	.84108	1.18894	.87133	1.14767	.90251	1.10802	.93469	1.06987	56
5	.84158	1.18824	.87184	1.14699	.90304	1.10737	.93524	1.06925	55
6	.84208	1.18754	.87236	1.14632	.90357	1.10672	.93578	1.06862	54
7	.84258	1.18684	.87287	1.14565	.90410	1.10607	.93633	1.06800	53
8	.84307	1.18614	.87338	1.14498	.90463	1.10543	.93688	1.06738	52
9	.84357	1.18544	.87389	1.14430	.90516	1.10478	.93742	1.06676	51
10	.84407	1.18474	.87441	1.14363	.90569	1.10414	.93797	1.06613	50
11	.84457	1.18404	.87492	1.14296	.90621	1.10349	.93852	1.06551	49
12	.84507	1.18334	.87543	1.14229	.90674	1.10285	.93906	1.06489	48
13	.84556	1.18264	.87595	1.14162	.90727	1.10220	.93961	1.06427	47
14	.84606	1.18194	.87646	1.14095	.90781	1.10156	.94016	1.06365	46
15	.84656	1.18125	.87698	1.14028	.90834	1.10091	.94071	1.06303	45
16	.84706	1.18055	.87749	1.13961	.90887	1.10027	.94125	1.06241	44
17	.84756	1.17986	.87801	1.13894	.90940	1.09963	.94180	1.06179	43
18	.84806	1.17916	.87852	1.13828	.90993	1.09899	.94235	1.06117	42
19	.84856	1.17846	.87904	1.13761	.91046	1.09834	.94290	1.06056	41
20	.84906	1.17777	.87955	1.13694	.91099	1.09770	.94345	1.05994	40
21	.84956	1.17708	.88007	1.13627	.91153	1.09706	.94400	1.05932	39
22	.85006	1.17638	.88059	1.13561	.91206	1.09642	.94455	1.05870	38
23	.85057	1.17569	.88110	1.13494	.91259	1.09578	.94510	1.05809	37
24	.85107	1.17500	.88162	1.13428	.91313	1.09514	.94565	1.05747	36
25	.85157	1.17430	.88214	1.13361	.91366	1.09450	.94620	1.05685	35
26	.85207	1.17361	.88265	1.13295	.91419	1.09386	.94676	1.05624	34
27	.85257	1.17292	.88317	1.13228	.91473	1.09322	.94731	1.05562	33
28	.85307	1.17223	.88369	1.13162	.91526	1.09258	.94786	1.05501	32
29	.85358	1.17154	.88421	1.13096	.91580	1.09195	.94841	1.05439	31
30	.85408	1.17085	.88473	1.13029	.91633	1.09131	.94896	1.05378	30
31	.85458	1.17016	.88524	1.12963	.91687	1.09067	.94952	1.05317	29
32	.85509	1.16947	.88576	1.12897	.91740	1.09003	.95007	1.05255	28
33	.85559	1.16878	.88628	1.12831	.91794	1.08940	.95062	1.05194	27
34	.85609	1.16809	.88680	1.12765	.91847	1.08876	95118	1.05133	26
35	.85660	1.16741	.88732	1.12699	.91901	1.08813	.95173	1.05072	25
36	.85710	1.16672	.88784	1.12633	.91955	1.08749	.95229	1.05010	24
37	.85761	1.16603	.88836	1.12567	.92008	1.08686	.95284	1.04949	23
38	.85811	1.16535	.88888	1.12501	.92062	1.08622	.95340	1.04888	22
39	.85862	1.16466	.88940	1.12435	.92116	1.08559	.95395	1.04827	21
40	.85912	1.16398	.88992	1.12369	.92170	1.08496	.95451	1.04766	20
41	.85963	1.16329	.89045	1.12303	.92224	1.08432	.95506	1.04705	19
42	.86014	1.16261	.89097	1.12238	.92277	1.08369	.95562	1.04644	18
43	.86064	1.16192	.89149	1.12172	.92331	1.08306	.95618	1.04583	17
44	.86115	1.16124	.89201	1.12106	.92385	1.08243	.95673	1.04522	16
45	.86166	1.16056	.89253	1.12041	.92439	1.08179	.95729	1.04461	15
46	.86216	1.15987	.89306	1.11975	.92493	1.08116	.95785	1.04401	14
47	.86267	1.15919	.89358	1.11909	.92547	1.08053	.95841	1.04340	13
48	.86318	1.15851	.89410	1.11844	.92601	1.07990	.95897	1.04279	12
49	.86368	1.15783	.89463	1.11778	.92655	1.07927	.95952	1.04218	11
50	.86419	1.15715	.89515	1.11713	.92709	1.07864	.96008	1.04158	10
51	.86470	1.15647	.89567	1.11648	.92763	1.07801	.96064	1.04097	9
52	.86521	1.15579	.89620	1.11582	.92817	1.07738	.96120	1.04036	8
53	.86572	1.15511	.89672	1.11517	.92872	1.07676	.96176	1.03976	7
54	.86623	1.15443	.89725	1.11452	.92926	1.07613	.96232	1.03915	6
55	.86674	1.15375	.89777	1.11387	.92980	1.07550	.96288	1.03855	5
56	.86725	1.15308	.89830	1.11321	.93034	1.07487	.96344	1.03794	4
57	.86776	1.15240	.89883	1.11256	.93088	1.07425	.96400	1.03734	3
58	.86827	1.15172	.89035	1.11191	.93143	1.07362	.96457	1.03674	2
59	.86878	1.15104	.89088	1.11126	.93197	1.07299	.96513	1.03613	1
60	.86929	1.15037	.90040	1.11061	.93252	1.07237	.96569	1.03553	0
′	CO-TAN	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN	TAN.	′
	49°		48°		47°		46°		

	44°				44°				44°		
′	Tan.	Co-tan.	′	′	Tan.	Co-tan.	′	′	Tan.	Co-tan.	′
0	.96569	1.03553	60	21	.97756	1.02295	39	41	.98901	1.01112	19
1	.96625	1.03493	59	22	.97813	1.02236	38	42	.98958	1.01053	18
2	.96681	1.03433	58	23	.97870	1.02176	37	43	.99016	1.00994	17
3	.96738	1.03372	57	24	.97927	1.02117	36	44	.99073	1.00935	16
4	.96794	1.03312	56	25	.97984	1.02057	35	45	.99131	1.00876	15
5	.96850	1.03252	55	26	.98041	1.01998	34	46	.99189	1.00818	14
6	.96907	1.03192	54	27	.98098	1.01939	33	47	.99247	1.00759	13
7	.96963	1.03132	53	28	.98155	1.01879	32	48	.99304	1.00701	12
8	.97020	1.03072	52	29	.98213	1.01820	31	49	.99362	1.00642	11
9	.97076	1.03012	51	30	.98270	1.01761	30	50	.99420	1.00583	10
10	.97133	1.02952	50	31	.98327	1.01702	29	51	.99478	1.00525	9
11	.97189	1.02892	49	32	.98384	1.01642	28	52	.99536	1.00467	8
12	.97246	1.02832	48	33	.98441	1.01583	27	53	.99594	1.00408	7
13	.97302	1.02772	47	34	.98499	1.01524	26	54	.99652	1.00350	6
14	.97359	1.02713	46	35	.98556	1.01465	25	55	.99710	1.00291	5
15	.97416	1.02653	45	36	.98613	1.01406	24	56	.99768	1.00233	4
16	.97472	1.02593	44	37	.98671	1.01347	23	57	.99826	1.00175	3
17	.97529	1.02533	43	38	.98728	1.01288	22	58	.99884	1.00116	2
18	.97586	1.02474	42	39	.98786	1.01229	21	59	.99942	1.00058	1
19	.97643	1.02414	41	40	.98843	1.01170	20	60	1	1	0
20	.97700	1.02355	40								
′	Co-tan.	Tan.	′	′	Co-tan.	Tan.	′	′	Co-tan.	Tan.	′
	45°				45°				45°		

NATURAL SINES AND COSINES

	0°				0°				0°		
′	Sine	Cosine	′	′	Sine	Cosine	′		Sine	Cosine	′
0	.00000	1	60	21	.00611	.99998	39	41	.01193	.99993	19
1	.00029	1	59	22	.00640	.99998	38	42	.01222	.99993	18
2	.00058	1	58	23	.00669	.99998	37	43	.01251	.99992	17
3	.00087	1	57	24	.00698	.99998	36	44	.01280	.99992	16
4	.00116	1	56	25	.00727	.99997	35	45	.01309	.99991	15
5	.00145	1	55	26	.00756	.99997	34	46	.01338	.99991	14
6	.00175	1	54	27	.00785	.99997	33	47	.01367	.99991	13
7	.00204	1	53	28	.00814	.99997	32	48	.01396	.99990	12
8	.00233	1	52	29	.00844	.99996	31	49	.01425	.99990	11
9	.00262	1	51	30	.00873	.99996	30	50	.01454	.99989	10
10	.00291	1	50	31	.00902	.99996	29	51	.01483	.99989	9
11	.00320	.99999	49	32	.00931	.99996	28	52	.01513	.99989	8
12	.00349	.99999	48	33	.00960	.99995	27	53	.01542	.99988	7
13	.00378	.99999	47	34	.00989	.99995	26	54	.01571	.99988	6
14	.00407	.99999	46	35	.01018	.99995	25	55	.01600	.99987	5
15	.00436	.99999	45	36	.01047	.99995	24	56	.01629	.99987	4
16	.00465	.99999	44	37	.01076	.99994	23	57	.01658	.99986	3
17	.00495	.99999	43	38	.01105	.99994	22	58	.01687	.99986	2
18	.00524	.99999	42	39	.01134	.99994	21	59	.01716	.99985	1
19	.00553	.99998	41	40	.01164	.99993	20	60	.01745	.99985	0
20	.00582	.99998	40								
′	Cosine	Sine	′	′	Cosine	Sine	′	′	Cosine	Sine	′
	89°				89°				89°		

	1°		2°		3°		4°		
′	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	′
0	.01745	.99985	.03490	.99939	.05234	.99863	.06976	.99756	60
1	.01774	.99984	.03519	.99938	.05263	.99861	.07005	.99754	59
2	.01803	.99984	.03548	.99937	.05292	.99860	.07034	.99752	58
3	.01832	.99983	.03577	.99936	.05321	.99858	.07063	.99750	57
4	.01862	.99983	.03606	.99935	.05350	.99857	.07092	.99748	56
5	.01891	.99982	.03635	.99934	.05379	.99855	.07121	.99746	55
6	.01920	.99982	.03664	.99933	.05408	.99854	.07150	.99744	54
7	.01949	.99981	.03693	.99932	.05437	.99852	.07179	.99742	53
8	.01978	.99980	.03723	.99931	.05466	.99851	.07208	.99740	52
9	.02007	.99980	.03752	.99930	.05495	.99849	.07237	.99738	51
10	.02036	.99979	.03781	.99929	.05524	.99847	.07266	.99736	50
11	.02065	.99979	.03810	.99927	.05553	.99846	.07295	.99734	49
12	.02094	.99978	.03839	.99926	.05582	.99844	.07324	.99731	48
13	.02123	.99977	.03868	.99925	.05611	.99842	.07353	.99729	47
14	.02152	.99977	.03897	.99924	.05640	.99841	.07382	.99727	46
15	.02181	.99976	.03926	.99923	.05669	.99839	.07411	.99725	45
16	.02211	.99976	.03955	.99922	.05698	.99838	.07440	.99723	44
17	.02240	.99975	.03984	.99921	.05727	.99836	.07469	.99721	43
18	.02269	.99974	.04013	.99919	.05756	.99834	.07498	.99719	42
19	.02298	.99974	.04042	.99918	.05785	.99833	.07527	.99716	41
20	.02327	.99973	.04071	.99917	.05814	.99831	.07556	.99714	40
21	.02356	.99972	.04100	.99916	.05844	.99829	.07585	.99712	39
22	.02385	.99972	.04129	.99915	.05873	.99827	.07614	.99710	38
23	.02414	.99971	.04159	.99913	.05902	.99826	.07643	.99708	37
24	.02443	.99970	.04188	.99912	.05931	.99824	.07672	.99705	36
25	.02472	.99969	.04217	.99911	.05960	.99822	.07701	.99703	35
26	.02501	.99969	.04246	.99910	.05989	.99821	.07730	.99701	34
27	.02530	.99968	.04275	.99909	.06018	.99819	.07759	.99699	33
28	.02560	.99967	.04304	.99907	.06047	.99817	.07788	.99696	32
29	.02589	.99966	.04333	.99906	.06076	.99815	.07817	.99694	31
30	.02618	.99966	.04362	.99905	.06105	.99813	.07846	.99692	30
31	.02647	.99965	.04391	.99904	.06134	.99812	.07875	.99689	29
32	.02676	.99964	.04420	.99902	.06163	.99810	.07904	.99687	28
33	.02705	.99963	.04449	.99901	.06192	.99808	.07933	.99685	27
34	.02734	.99963	.04478	.99900	.06221	.99806	.07962	.99683	26
35	.02763	.99962	.04507	.99898	.06250	.99804	.07991	.99680	25
36	.02792	.99961	.04536	.99897	.06279	.99803	.08020	.99678	24
37	.02821	.99960	.04565	.99896	.06308	.99801	.08049	.99676	23
38	.02850	.99959	.04594	.99894	.06337	.99799	.08078	.99673	22
39	.02879	.99959	.04623	.99893	.06366	.99797	.08107	.99671	21
40	.02908	.99958	.04653	.99892	.06395	.99795	.08136	.99668	20
41	.02938	.99957	.04682	.99890	.06424	.99793	.08165	.99666	19
42	.02967	.99956	.04711	.99889	.06453	.99792	.08194	.99664	18
43	.02996	.99955	.04740	.99888	.06482	.99790	.08223	.99661	17
44	.03025	.99954	.04769	.99886	.06511	.99788	.08252	.99659	16
45	.03054	.99953	.04798	.99885	.06540	.99786	.08281	.99657	15
46	.03083	.99952	.04827	.99883	.06569	.99784	.08310	.99654	14
47	.03112	.99952	.04856	.99882	.06598	.99782	.08339	.99652	13
48	.03141	.99951	.04885	.99881	.06627	.99780	.08368	.99649	12
49	.03170	.99950	.04914	.99879	.06656	.99778	.08397	.99647	11
50	.03199	.99949	.04943	.99878	.06685	.99776	.08426	.99644	10
51	.03228	.99948	.04972	.99876	.06714	.99774	.08455	.99642	9
52	.03257	.99947	.05001	.99875	.06743	.99772	.08484	.99639	8
53	.03286	.99946	.05030	.99873	.06773	.99770	.08513	.99637	7
54	.03316	.99945	.05059	.99872	.06802	.99768	.08542	.99635	6
55	.03345	.99944	.05088	.99870	.06831	.99766	.08571	.99632	5
56	.03374	.99943	.05117	.99869	.06860	.99764	.08600	.99630	4
57	.03403	.99942	.05146	.99867	.06889	.99762	.08629	.99627	3
58	.03432	.99941	.05175	.99866	.06918	.99760	.08658	.99625	2
59	.03461	.99940	.05205	.99864	.06947	.99758	.08687	.99622	1
60	.03490	.99939	.05234	.99863	.06976	.99756	.08716	.99619	0
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	88°		87°		86°		85°		

′	5°		6°		7°		8°		′
	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	
0	.08716	.99619	.10453	.99452	.12187	.99255	.13917	.99027	60
1	.08745	.99617	.10482	.99449	.12216	.99251	.13946	.99023	59
2	.08774	.99614	.10511	.99446	.12245	.99248	.13975	.99019	58
3	.08803	.99612	.10540	.99443	.12274	.99244	.14004	.99015	57
4	.08831	.99609	.10569	.99440	.12302	.99240	.14033	.99011	56
5	.08860	.99607	.10597	.99437	.12331	.99237	.14061	.99006	55
6	.08889	.99604	.10626	.99434	.12360	.99233	.14090	.99002	54
7	.08918	.99602	.10655	.99431	.12389	.99230	.14119	.98998	53
8	.08947	.99599	.10684	.99428	.12418	.99226	.14148	.98994	52
9	.08976	.99596	.10713	.99424	.12447	.99222	.14177	.98990	51
10	.09005	.99594	.10742	.99421	.12476	.99219	.14205	.98986	50
11	.09034	.99591	.10771	.99418	.12504	.99215	.14234	.98982	49
12	.09063	.99588	.10800	.99415	.12533	.99211	.14263	.98978	48
13	.09092	.99586	.10829	.99412	.12562	.99208	.14292	.98973	47
14	.09121	.99583	.10858	.99409	.12591	.99204	.14320	.98969	46
15	.09150	.99580	.10887	.99406	.12620	.99200	.14349	.98965	45
16	.09179	.99578	.10916	.99402	.12649	.99197	.14378	.98961	44
17	.09208	.99575	.10945	.99399	.12678	.99193	.14407	.98957	43
18	.09237	.99572	.10973	.99396	.12706	.99189	.14436	.98953	42
19	.09266	.99570	.11002	.99393	.12735	.99186	.14464	.98948	41
20	.09295	.99567	.11031	.99390	.12764	.99182	.14493	.98944	40
21	.09324	.99564	.11060	.99386	.12793	.99178	.14522	.98940	39
22	.09353	.99562	.11089	.99383	.12822	.99175	.14551	.98936	38
23	.09382	.99559	.11118	.99380	.12851	.99171	.14580	.98931	37
24	.09411	.99556	.11147	.99377	.12880	.99167	.14608	.98927	36
25	.09440	.99553	.11176	.99374	.12908	.99163	.14637	.98923	35
26	.09469	.99551	.11205	.99370	.12937	.99160	.14666	.98919	34
27	.09498	.99548	.11234	.99367	.12966	.99156	.14695	.98914	33
28	.09527	.99545	.11263	.99364	.12995	.99152	.14723	.98910	32
29	.09556	.99542	.11291	.99360	.13024	.99148	.14752	.98906	31
30	.09585	.99540	.11320	.99357	.13053	.99144	.14781	.98902	30
31	.09614	.99537	.11349	.99354	.13081	.99141	.14810	.98897	29
32	.09642	.99534	.11378	.99351	.13110	.99137	.14838	.98893	28
33	.09671	.99531	.11407	.99347	.13139	.99133	.14867	.98889	27
34	.09700	.99528	.11436	.99344	.13168	.99129	.14896	.98884	26
35	.09729	.99526	.11465	.99341	.13197	.99125	.14925	.98880	25
36	.09758	.99523	.11494	.99337	.13226	.99122	.14954	.98876	24
37	.09787	.99520	.11523	.99334	.13254	.99118	.14982	.98871	23
38	.09816	.99517	.11552	.99331	.13283	.99114	.15011	.98867	22
39	.09845	.99514	.11580	.99327	.13312	.99110	.15040	.98863	21
40	.09874	.99511	.11609	.99324	.13341	.99106	.15069	.98858	20
41	.09903	.99508	.11638	.99320	.13370	.99102	.15097	.98854	19
42	.09932	.99506	.11667	.99317	.13399	.99098	.15126	.98849	18
43	.09961	.99503	.11696	.99314	.13427	.99094	.15155	.98845	17
44	.09990	.99500	.11725	.99310	.13456	.99091	.15184	.98841	16
45	.10019	.99497	.11754	.99307	.13485	.99087	.15212	.98836	15
46	.10048	.99494	.11783	.99303	.13514	.99083	.15241	.98832	14
47	.10077	.99491	.11812	.99300	.13543	.99079	.15270	.98827	13
48	.10106	.99488	.11840	.99297	.13572	.99075	.15299	.98823	12
49	.10135	.99485	.11869	.99293	.13600	.99071	.15327	.98818	11
50	.10164	.99482	.11898	.99290	.13629	.99067	.15356	.98814	10
51	.10192	.99479	.11927	.99286	.13658	.99063	.15385	.98809	9
52	.10221	.99476	.11956	.99283	.13687	.99059	.15414	.98805	8
53	.10250	.99473	.11985	.99279	.13716	.99055	.15442	.98800	7
54	.10279	.99470	.12014	.99276	.13744	.99051	.15471	.98796	6
55	.10308	.99467	.12043	.99272	.13773	.99047	.15500	.98791	5
56	.10337	.99464	.12071	.99269	.13802	.99043	.15529	.98787	4
57	.10366	.99461	.12100	.99265	.13831	.99039	.15557	.98782	3
58	.10395	.99458	.12129	.99262	.13860	.99035	.15586	.98778	2
59	.10424	.99455	.12158	.99258	.13889	.99031	.15615	.98773	1
60	.10453	.99452	.12187	.99255	.13917	.99027	.15643	.98769	0
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	84°		83°		82°		81°		

′	9°		10°		11°		12°		′
	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	
0	.15643	.98769	.17365	.98481	.19081	.98163	.20791	.97815	60
1	.15672	.98764	.17393	.98476	.19109	.98157	.20820	.97809	59
2	.15701	.98760	.17422	.98471	.19138	.98152	.20848	.97803	58
3	.15730	.98755	.17451	.98466	.19167	.98146	.20877	.97797	57
4	.15758	.98751	.17479	.98461	.19195	.98140	.20905	.97791	56
5	.15787	.98746	.17508	.98455	.19224	.98135	20933	.97784	55
6	.15816	.98741	.17537	.98450	.19252	.98129	.20962	.97778	54
7	.15845	.98737	.17565	.98445	.19281	.98124	.20990	.97772	53
8	.15873	.98732	.17594	.98440	.19309	.98118	.21019	.97766	52
9	.15902	.98728	.17623	.98435	.19338	.98112	.21047	.97760	51
10	.15931	.98723	.17651	.98430	.19366	.98107	.21076	.97754	50
11	.15959	.98718	.17680	.98425	.19395	.98101	.21104	.97748	49
12	.15988	.98714	.17708	.98420	.19423	.98096	.21132	.97742	48
13	.16017	.98709	.17737	.98414	.19452	.98090	.21161	.97735	47
14	.16046	.98704	.17766	.98409	.19481	.98084	.21189	.97729	46
15	.16074	.98700	.17794	.98404	.19509	.98079	.21218	.97723	45
16	.16103	.98695	.17823	.98399	.19538	.98073	.21246	.97717	44
17	.16132	.98690	.17852	.98394	.19566	.98067	.21275	.97711	43
18	.16160	.98685	.17880	.98389	.19595	.98061	.21303	.97705	42
19	.16189	.98681	.17909	.98383	.19623	.98056	.21331	.97698	41
20	.16218	.98676	.17937	.98378	.19652	.98050	.21360	.97692	40
21	.16246	.98671	.17966	.98373	.19680	.98044	.21388	.97686	39
22	.16275	.98667	.17995	.98368	.19709	.98039	.21417	.97680	38
23	.16304	.98662	.18023	.98362	.19737	.98033	.21445	.97673	37
24	.16333	.98657	.18052	.98357	.19766	.98027	.21474	.97667	36
25	.16361	.98652	.18081	.98352	.19794	.98021	.21502	.97661	35
26	.16390	.98648	.18109	.98347	.19823	.98016	.21530	.97655	34
27	.16419	.98643	.18138	.98341	.19851	.98010	.21559	.97648	33
28	.16447	.98638	.18166	.98336	.19880	.98004	.21587	.97642	32
29	.16476	.98633	.18195	.98331	.19908	.97997	.21616	.97636	31
30	.16505	.98629	.18224	.98325	.19937	.97992	.21644	.97630	30
31	.16533	.98624	.18252	.98320	.19965	.97987	.21672	.97623	29
32	.16562	.98619	.18281	.98315	.19994	.97981	.21701	.97617	28
33	.16591	.98614	.18309	.98310	.20022	.97975	.21729	.97611	27
34	.16620	.98609	.18338	.98304	.20051	.97969	.21758	.97604	26
35	.16648	.98604	.18367	.98299	.20079	.97963	.21786	.97598	25
36	.16677	.98600	.18395	.98294	.20108	.97958	.21814	.97592	24
37	.16706	.98595	.18424	.98288	.20136	.97952	.21843	.97585	23
38	.16734	.98590	.18452	.98283	.20165	.97946	.21871	.97579	22
39	.16763	.98585	.18481	.98277	.20193	.97940	.21899	.97573	21
40	.16792	.98580	.18509	.98272	.20222	.97934	.21928	.97566	20
41	.16820	.98575	.18538	.98267	.20250	.97928	.21956	.97560	19
42	.16849	.98570	.18567	.98261	.20279	.97922	.21985	.97553	18
43	.16878	.98565	.18595	.98256	.20307	.97916	.22013	.97547	17
44	.16906	.98561	.18624	.98250	.20336	.97910	.22041	.97541	16
45	.16935	.98556	.18652	.98245	.20364	.97905	.22070	.97534	15
46	.16964	.98551	.18681	.98240	.20393	.97899	.22098	.97528	14
47	.16992	.98546	.18710	.98234	.20421	.97893	.22126	.97521	13
48	.17021	.98541	.18738	.98229	.20450	.97887	.22155	.97515	12
49	.17050	.98536	.18767	.98223	.20478	.97881	.22183	.97508	11
50	.17078	.98531	.18795	.98218	.20507	.97875	.22212	.97502	10
51	.17107	.98526	.18824	.98212	.20535	.97869	.22240	.97496	9
52	.17136	.98521	.18852	.98207	.20563	.97863	.22268	.97489	8
53	.17164	.98516	.18881	.98201	.20592	.97857	.22297	.97483	7
54	.17193	.98511	.18910	.98196	.20620	.97851	.22325	.97476	6
55	.17222	.98506	.18938	.98190	.20649	.97845	.22353	.97470	5
56	.17250	.98501	.18967	.98185	.20677	.97839	.22382	.97463	4
57	.17279	.98406	.18995	.98179	.20706	.97833	.22410	.97457	3
58	.17308	.98491	.19024	.98174	.20734	.97827	.22438	.97450	2
59	.17336	.98486	.19052	.98168	.20763	.97821	.22467	.97444	1
60	.17365	.98481	.10081	.98163	.20791	.97815	.22495	.97437	0
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	80°		79°		78°		77°		

	13°		14°		15°		16°		
′	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	′
0	.22495	.97437	.24192	.97030	.25882	.96593	.27564	.96126	60
1	.22523	.97430	.24220	.97023	.25910	.96585	.27592	.96118	59
2	.22552	.97424	.24249	.97015	.25938	.96578	.27620	.96110	58
3	.22580	.97417	.24277	.97008	.25966	.96570	.27648	.96102	57
4	.22608	.97411	.24305	.97001	.25994	.96562	.27676	.96094	56
5	.22637	.97404	.24333	.96994	.26022	.96555	.27704	.96086	55
6	.22665	.97398	.24362	.96987	.26050	.96547	.27731	.96078	54
7	.22693	.97391	.24390	.96980	.26079	.96540	.27759	.96070	53
8	.22722	.97384	.24418	.96973	.26107	.96532	.27787	.96062	52
9	.22750	.97378	.24446	.96966	.26135	.96524	.27815	.96054	51
10	.22778	.97371	.24474	.96959	.26163	.96517	.27843	.96046	50
11	.22807	.97365	.24503	.96952	.26191	.96509	.27871	.96037	49
12	.22835	.97358	.24531	.96945	.26219	.96502	.27899	.96029	48
13	.22863	.97351	.24559	.96937	.26247	.96494	.27927	.96021	47
14	.22892	.97345	.24587	.96930	.26275	.96486	.27955	.96013	46
15	.22920	.97338	.24615	.96923	.26303	.96479	.27983	.96005	45
16	.22948	.97331	.24644	.96916	.26331	.96471	.28011	.95997	44
17	.22977	.97325	.24672	.96909	.26359	.96463	.28039	.95989	43
18	.23005	.97318	.24700	.96902	.26387	.96456	.28067	.95981	42
19	.23033	.97311	.24728	.96894	.26415	.96448	.28095	.95972	41
20	.23062	.97304	.24756	.96887	.26443	.96440	.28123	.95964	40
21	.23090	.97298	.24784	.96880	.26471	.96433	.28150	.95956	39
22	.23118	.97291	.24813	.96873	.26500	.96425	.28178	.95948	38
23	.23146	.97284	.24841	.96866	.26528	.96417	.28206	.95940	37
24	.23175	.97278	.24869	.96858	.26556	.96410	.28234	.95931	36
25	.23203	.97271	.24897	.96851	.26584	.96402	.28262	.95923	35
26	.23231	.97264	.24925	.96844	.26612	.96394	.28290	.95915	34
27	.23260	.97257	.24954	.96837	.26640	.96386	.28318	.95907	33
28	.23288	.97251	.24982	.96829	.26668	.96379	.28346	.95898	32
29	.23316	.97244	.25010	.96822	.26696	.96371	.28374	.95890	31
30	.23345	.97237	.25038	.96815	.26724	.96363	.28402	.95882	30
31	.23373	.97230	.25066	.96807	.26752	.96355	.28429	.95874	29
32	.23401	.97223	.25094	.96800	.26780	.96347	.28457	.95865	28
33	.23429	.97217	.25122	.96793	.26808	.96340	.28485	.95857	27
34	.23458	.97210	.25151	.96786	.26836	.96332	.28513	.95849	26
35	.23486	.97203	.25179	.96778	.26864	.96324	.28541	.95841	25
36	.23514	.97196	.25207	.96771	.26892	.96316	.28569	.95832	24
37	.23542	.97189	.25235	.96764	.26920	.96308	.28597	.95824	23
38	.23571	.97182	.25263	.96756	.26948	.96301	.28625	.95816	22
39	.23599	.97176	.25291	.96749	.26976	.96293	.28652	.95807	21
40	.23627	.97169	.25320	.96742	.27004	.96285	.28680	.95799	20
41	.23656	.97162	.25348	.96734	.27032	.96277	.28708	.95791	19
42	.23684	.97155	.25376	.96727	.27060	.96269	.28736	.95782	18
43	.23712	.97148	.25404	.96719	.27088	.96261	.28764	.95774	17
44	.23740	.97141	.25432	.96712	.27116	.96253	.28792	.95766	16
45	.23769	.97134	.25460	.96705	.27144	.96246	.28820	.95757	15
46	.23797	.97127	.25488	.96697	.27172	.96238	.28847	.95749	14
47	.23825	.97120	.25516	.96690	.27200	.96230	.28875	.95740	13
48	.23853	.97113	.25545	.96682	.27228	.96222	.28903	.95732	12
49	.23882	.97106	.25573	.96675	.27256	.96214	.28931	.95724	11
50	.23910	.97100	.25601	.96667	.27284	.96206	.28959	95715	10
51	.23938	.97093	.25629	.96660	.27312	.96198	.28987	.95707	9
52	.23966	.97086	.25657	.96653	.27340	.96190	.29015	.95698	8
53	.23995	.97079	.25685	.96645	.27368	.96182	.29042	.95690	7
54	.24023	.97072	.25713	.96638	.27396	.96174	.20070	.95681	6
55	.24051	.97065	.25741	.96630	.27424	.96166	.29098	.95673	5
56	.24079	.97058	.25769	.96623	.27452	.96158	.29126	.95664	4
57	.24108	.97051	.25798	.96615	.27480	.96150	.29154	.95656	3
58	.24136	.97044	.25826	.96608	.27508	.96142	.29182	.95647	2
59	.24164	.97037	.25854	.96600	.27536	.96134	.29209	.95639	1
60	.24192	.97030	.25882	.96593	.27564	.96126	.29237	.95630	0
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	76°		75°		74°		73°		

′	17°		18°		19°		20°		′
	Sine	**Cosine**	**Sine**	**Cosine**	**Sine**	**Cosine**	**Sine**	**Cosine**	
0	·29237	·95630	·30902	·95106	·32557	·94552	·34202	·93969	60
1	·29265	·95622	·30929	·95097	·32584	·94542	·34229	·93959	59
2	·29293	·95613	·30957	·95088	·32612	·94533	·34257	·93949	58
3	·29321	·95605	·30985	·95079	·32639	·94523	·34284	·93939	57
4	·29348	·95596	·31012	·95070	·32667	·94514	·34311	·93929	56
5	·29376	·95588	·31040	·95061	·32694	·94504	·34339	·93919	55
6	·29404	·95579	·31068	·95052	·32722	·94495	·34366	·93909	54
7	·29432	·95571	·31095	·95043	·32749	·94485	·34393	·93899	53
8	·29460	·95562	·31123	·95033	·32777	·94476	·34421	·93889	52
9	·29487	·95554	·31151	·95024	·32804	·94466	·34448	·93879	51
10	·29515	·95545	·31178	·95015	·32832	·94457	·34475	·93869	50
11	·29543	·95536	·31206	·95006	·32859	·94447	·34503	·93859	49
12	·29571	·95528	·31233	·94997	·32887	·94438	·34530	·93849	48
13	·29599	·95519	·31261	·94988	·32914	·94428	·34557	·93839	47
14	·29626	·95511	·31289	·94979	·32942	·94418	·34584	·93829	46
15	·29654	·95502	·31316	·94970	·32969	·94409	·34612	·93819	45
16	·29682	·95493	·31344	·94961	·32997	·94399	·34639	·93809	44
17	·29710	·95485	·31372	·94952	·33024	·94390	·34666	·93799	43
18	·29737	·95476	·31399	·94943	·33051	·94380	·34694	·93789	42
19	·29765	·95467	·31427	·94933	·33079	·94370	·34721	·93779	41
20	·29793	·95459	·31454	·94924	·33106	·94361	·34748	·93769	40
21	·29821	·95450	·31482	·94915	·33134	·94351	·34775	·93759	39
22	·29849	·95441	·31510	·94906	·33161	·94342	·34803	·93748	38
23	·29876	·95433	·31537	·94897	·33189	94332	·34830	·93738	37
24	·29904	·95424	·31565	·94888	·33216	·94322	·34857	·93728	36
25	·29932	·95415	·31593	·94878	·33244	·94313	·34884	·93718	35
26	·29960	·95407	·31620	·94869	·33271	·94303	·34912	·93708	34
27	·29987	·95398	·31648	·94860	·33298	·94293	·34939	·93698	33
28	·30015	·95389	·31675	·94851	·33326	·94284	·34966	·93688	32
29	·30043	·95380	·31703	·94842	·33353	·94274	·34993	·93677	31
30	·30071	·95372	·31730	·94832	·33381	·94264	·35021	·93667	30
31	·30098	·95363	·31758	·94823	·33408	·94254	·35048	·93657	29
32	·30126	·95354	·31786	·94814	·33436	·94245	·35075	·93647	28
33	·30154	·95345	·31813	·94805	·33463	·94235	·35102	·93637	27
34	·30182	·95337	·31841	·94795	·33490	·94225	·35130	·93626	26
35	·30209	·95328	31868	·94786	·33518	·94215	·35157	·93616	25
36	·30237	·95319	·31896	·94777	·33545	·94206	·35184	·93606	24
37	·30265	·95310	·31923	·94768	·33573	·94196	·35211	·93596	23
38	·30292	·95301	·31951	·94758	·33600	·94186	·35239	·93585	22
39	·30320	·95293	·31979	·94749	·33627	·94176	·35266	·93575	21
40	·30348	·95284	·32006	·94740	·33655	·94167	·35293	·93565	20
41	·30376	·95275	·32034	·94730	·33682	·94157	·35320	·93555	19
42	·30403	·95266	·32061	·94721	·33710	·94147	·35347	·93544	18
43	·30431	·95257	·32089	·94712	·33737	·94137	·35375	·93534	17
44	·30459	·95248	·32116	·94702	·33764	·94127	·35402	·93524	16
45	·30486	·95240	·32144	·94693	·33792	·94118	·35429	·93514	15
46	·30514	·95231	·32171	·94684	·33819	·94108	·35456	·93503	14
47	·30542	·95222	·32199	·94674	·33846	·94098	·35484	·93493	13
48	·30570	·95213	·32227	·94665	·33874	·94088	·35511	·93483	12
49	·30597	·95204	·32254	·94656	·33901	·94078	·35538	·93472	11
50	·30625	·95195	·32282	·94646	·33929	·94068	·35565	·93462	10
51	·30653	·95186	·32309	·94637	·33956	·94058	·35592	·93452	9
52	·30680	·95177	·32337	·94627	·33983	·94049	·35619	·93441	8
53	·30708	·95168	·32364	·94618	·34011	·94039	·35647	·93431	7
54	·30736	·95159	·32392	·94609	·34038	·94029	·35674	·93420	6
55	·30763	·95150	·32419	·94599	·34065	·94019	·35701	·93410	5
56	·30791	·95142	·32447	·94590	·34093	·94009	·35728	·93400	4
57	·30819	·95133	·32474	·94580	·34120	·93999	·35755	·93389	3
58	·30846	·95124	·32502	·94571	·34147	·93989	·35782	·93379	2
59	·30874	·95115	·32529	·94561	·34175	·93979	·35810	·93368	1
60	·30902	·95106	·32557	·94552	·34202	·93969	·35837	·93358	0
′	**Cosine**	**Sine**	**Cosine**	**Sine**	**Cosine**	**Sine**	**Cosine**	**Sine**	′
	72°		71°		70°		69°		

	21°		22°		23°		24°		
′	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	′
0	.35837	.93358	.37461	.92718	.39073	.92050	.40674	.91355	60
1	.35864	.93348	.37488	.92707	.39100	.92039	.40700	.91343	59
2	.35891	.93337	.37515	.92697	.39127	.92028	.40727	.91331	58
3	.35918	.93327	.37542	.92686	.39153	.92016	.40753	.91319	57
4	.35945	.93316	.37569	.92675	.39180	.92005	.40780	.91307	56
5	.35973	.93306	.37595	.92664	.39207	.91994	.40806	.91295	55
6	.36000	.93295	.37622	.92653	.39234	.91982	.40833	.91283	54
7	.36027	.93285	.37649	.92642	.39260	.91971	.40860	.91272	53
8	.36054	.93274	.37676	.92631	.39287	.91959	.40886	.91260	52
9	.36081	.93264	.37703	.92620	.39314	.91948	.40913	.91248	51
10	.36108	.93253	.37730	.92609	.39341	.91936	.40939	.91236	50
11	.36135	.93243	.37757	.92598	.39367	.91925	.40966	.91224	49
12	.36162	.93232	.37784	.92587	.39394	.91914	.40992	.91212	48
13	.36190	.93222	.37811	.92576	.39421	.91902	.41019	.91200	47
14	.36217	.93211	.37838	.92565	.39448	.91891	.41045	.91188	46
15	.36244	.93201	.37865	.92554	.39474	.91879	.41072	.91176	45
16	.36271	.93190	.37892	.92543	.39501	.91868	.41098	.91164	44
17	.36298	.93180	.37919	.92532	.39528	.91856	.41125	.91152	43
18	.36325	.93169	.37946	.92521	.39555	.91845	.41151	.91140	42
19	.36352	.93159	.37973	.92510	.39581	.91833	.41178	.91128	41
20	.36379	.93148	.37999	.92499	.39608	.91822	.41204	.91116	40
21	.36406	.93137	.38026	.92488	.39635	.91810	.41231	.91104	39
22	.36434	.93127	.38053	.92477	.39661	.91799	.41257	.91092	38
23	.36461	.93116	.38080	.92466	.39688	.91787	.41284	.91080	37
24	.36488	.93106	.38107	.92455	.39715	.91775	.41310	.91068	36
25	.36515	.93095	.38134	.92444	.39741	.91764	.41337	.91056	35
26	.36542	.93084	.38161	.92432	.39768	.91752	.41363	.91044	34
27	.36569	.93074	.38188	.92421	.39795	.91741	.41390	.91032	33
28	.36596	.93063	.38215	.92410	.39822	.91729	.41416	.91020	32
29	.36623	.93052	.38241	.92399	.39848	.91718	.41443	.91008	31
30	.36650	.93042	.38268	.92388	.39875	.91706	.41469	.90996	30
31	.36677	.93031	.38295	.92377	.39902	.91694	.41496	.90984	29
32	.36704	.93020	.38322	.92366	.39928	.91683	.41522	.90972	28
33	.36731	.93010	.38349	.92355	.39955	.91671	.41549	.90960	27
34	.36758	.92999	.38376	.92343	.39982	.91660	.41575	.90948	26
35	.36785	.92988	.38403	.92332	.40008	.91648	.41602	.90936	25
36	.36812	.92978	.38430	.92321	.40035	.91636	.41628	.90924	24
37	.36839	.92967	.38456	.92310	.40062	.91625	.41655	.90911	23
38	.36867	.92956	.38483	.92299	.40088	.91613	.41681	.90899	22
39	.36894	.92945	.38510	.92287	.40115	.91601	.41707	.90887	21
40	.36921	.92935	.38537	.92276	.40141	.91590	.41734	.90875	20
41	.36948	.92924	.38564	.92265	.40168	.91578	.41760	.90863	19
42	.36975	.92913	.38591	.92254	.40195	.91566	.41787	.90851	18
43	.37002	.92902	.38617	.92243	.40221	.91555	.41813	.90839	17
44	.37029	.92892	.38644	.92231	.40248	.91543	.41840	.90826	16
45	.37056	.92881	.38671	.92220	.40275	.91531	.41866	.90814	15
46	.37083	.92870	.38698	.92209	.40301	.91519	.41892	.90802	14
47	.37110	.92859	.38725	.92198	.40328	.91508	.41919	.90790	13
48	.37137	.92849	.38752	.92186	.40355	.91496	.41945	.90778	12
49	.37164	.92838	.38778	.92175	.40381	.91484	.41972	.90766	11
50	.37191	.92827	.38805	.92164	.40408	.91472	.41998	.90753	10
51	.37218	.92816	.38832	.92152	.40434	.91461	.42024	.90741	9
52	.37245	.92805	.38859	.92141	.40461	.91449	.42051	.90729	8
53	.37272	.92794	.38886	.92130	.40488	.91437	.42077	.90717	7
54	.37299	.92784	.38912	.92119	.40514	.91425	.42104	.90704	6
55	.37326	.92773	.38939	.92107	.40541	.91414	.42130	.90692	5
56	.37353	.92762	.38966	.92096	.40567	.91402	.42156	.90680	4
57	.37380	.92751	.38993	.92085	.40594	.91390	.42183	.90668	3
58	.37407	.92740	.39020	.92073	.40621	.91378	.42209	.90655	2
59	.37434	.92729	.39046	.92062	.40647	.91366	.42235	.90643	1
60	.37461	.92718	.39073	.92050	.40674	.91355	.42262	.90631	0
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	68°		67°		66°		65°		

	25°		26°		27°		28°		
′	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	′
0	.42262	.90631	.43837	.89879	.45399	.89101	.46947	.88295	60
1	.42288	.90618	.43863	.89867	.45425	.89087	.46973	.88281	59
2	.42315	.90606	.43889	.89854	.45451	.89074	.46999	.88267	58
3	.42341	.90594	.43916	.89841	.45477	.89061	.47024	.88254	57
4	.42367	.90582	.43942	.89828	.45503	.89048	.47050	.88240	56
5	.42394	.90569	.43968	.89816	.45529	.89035	.47076	.88226	55
6	.42420	.90557	.43994	.89803	.45554	.89021	.47101	.88213	54
7	.42446	.90545	.44020	.89790	.45580	.89008	.47127	.88199	53
8	.42473	.90532	.44046	.89777	.45606	.88995	.47153	.88185	52
9	.42499	.90520	.44072	.89764	.45632	.88981	.47178	.88172	51
10	.42525	.90507	.44098	.89752	.45658	.88968	.47204	.88158	50
11	.42552	.90495	.44124	.89739	.45684	.88955	.47229	.88144	49
12	.42578	.90483	.44151	.89726	.45710	.88942	.47255	.88130	48
13	.42604	.90470	.44177	.89713	.45736	.88928	.47281	.88117	47
14	.42631	.90458	.44203	.89700	.45762	.88915	.47306	.88103	46
15	.42657	.90446	.44229	.89687	.45787	.88902	.47332	.88089	45
16	.42683	.90433	.44255	.89674	.45813	.88888	.47358	.88075	44
17	.42709	.90421	.44281	.89662	.45839	.88875	.47383	.88062	43
18	.42736	.90408	.44307	.89649	.45865	.88862	.47409	.88048	42
19	.42762	.90396	.44333	.89636	.45891	.88848	.47434	.88034	41
20	.42788	.90383	44359	.89623	.45917	.88835	.47460	.88020	40
21	.42815	.90371	.44385	.89610	.45042	.88822	.47486	.88006	39
22	.42841	.90358	.44411	.89597	.45968	.88808	.47511	.87993	38
23	.42867	.90346	.44437	.89584	.45994	.88795	.47537	.87979	37
24	.42894	.90334	.44464	.89571	.46020	.88782	.47562	.87965	36
25	.42920	.90321	.44490	.89558	.46046	.88768	.47588	.87951	35
26	.42946	.90309	.44516	.89545	.46072	.88755	.47614	.87937	34
27	.42972	.90296	.44542	.89532	.46097	.88741	.47639	.87923	33
28	.42999	.90284	.44568	.89519	.46123	.88728	.47665	.87909	32
29	.43025	.90271	.44594	.89506	.46149	.88715	.47690	.87896	31
30	.43051	.90259	.44620	89493	.46175	.88701	.47716	.87882	30
31	.43077	.90246	.44646	.89480	.46201	.88688	.47741	.87868	29
32	.43104	.90233	.44672	.89467	.46226	.88674	.47767	.87854	28
33	.43130	.90221	.44698	.89454	.46252	.88661	.47793	.87840	27
34	.43156	.90208	.44724	.89441	.46278	.88647	.47818	.87826	26
35	.43182	.90196	.44750	.89428	.46304	.88634	.47844	.87812	25
36	.43209	.90183	.44776	.89415	.46330	.88620	.47869	.87798	24
37	.43235	.90171	.44802	.89402	.46355	.88607	.47895	.87784	23
38	.43261	.90158	.44828	.89389	.46381	.88593	.47920	.87770	22
39	.43287	.90146	.44854	.89376	.46407	.88580	.47946	.87756	21
40	.43313	.90133	.44880	.89363	.46433	.88566	.47971	.87748	20
41	.43340	.90120	.44906	.89350	.46458	.88553	.47997	.87729	19
42	.43366	.90108	.44932	.89337	.46484	.88539	.48022	.87715	18
43	.43392	.90095	.44958	.89324	46510	.88526	.48048	.87701	17
44	.43418	.90082	.44984	.89311	.46536	.88512	.48073	.87687	16
45	.43445	.90070	.45010	.89298	.46561	.88499	.48099	.87673	15
46	.43471	.90057	.45036	.89285	.46587	.88485	.48124	.87659	14
47	.43497	.90045	.45062	.89272	.46613	.88472	.48150	.87645	13
48	.43523	.90032	.45088	.89259	.46639	.88458	.48175	.87631	12
49	.43549	.90019	.45114	.89245	.46664	.88445	.48201	.87617	11
50	.43575	.90007	.45140	.89232	.46690	.88431	.48226	.87603	10
51	.43602	.89094	.45166	.89219	.46716	.88417	.48252	.87589	9
52	.43628	.89981	45192	.89206	.46742	.88404	.48277	.87575	8
53	.43654	.89968	.45218	.89193	.46767	.88390	.48303	.87561	7
54	.43680	.89956	.45243	.89180	.46793	.88377	.48328	.87546	6
55	.43706	.89043	.45269	.89167	.46819	.88363	.48354	.87532	5
56	.43733	.89930	.45295	.89153	.46844	.88349	.48379	.87518	4
57	.43759	.89918	.45321	.89140	.46870	.88336	.48405	.87504	3
58	.43785	.89905	.45347	.89127	.46896	.88322	.48430	.87490	2
59	.43811	.89892	.45373	.89114	.46921	.88308	.48456	.87476	1
60	.43837	.89879	.45399	.89101	.46947	.88295	.48481	.87462	0
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	64°		63°		62°		61°		

	29°		30°		31°		32°		
′	SINE	COSINE	SINE	COSINE	SINE	COSINE	SINE	COSINE	′
0	.48481	.87462	.50000	.86603	.51504	.85717	.52992	.84805	60
1	.48506	.87448	.50025	.86588	.51529	.85702	.53017	.84789	59
2	.48532	.87434	.50050	.86573	.51554	.85687	.53041	.84774	58
3	.48557	.87420	.50076	.86559	.51579	.85672	.53066	.84759	57
4	.48583	.87406	.50101	.86544	.51604	.85657	.53091	.84743	56
5	.48608	.87391	.50126	.86530	.51628	.85642	.53115	.84728	55
6	.48634	.87377	.50151	.86515	.51653	.85627	.53140	.84712	54
7	.48659	.87363	.50176	.86501	.51678	.85612	.53164	.84697	53
8	.48684	.87349	.50201	.86486	.51703	.85597	.53189	.84681	52
9	.48710	.87335	.50227	.86471	.51728	.85582	.53214	.84666	51
10	.48735	.87321	.50252	.86457	.51753	.85567	.53238	.84650	50
11	.48761	.87306	.50277	.86442	.51778	.85551	.53263	.84635	49
12	.48786	.87292	.50302	.86427	.51803	.85536	.53288	.84619	48
13	.48811	.87278	.50327	.86413	.51828	.85521	.53312	.84604	47
14	.48837	.87264	.50352	.86398	.51852	.85506	.53337	.84588	46
15	.48862	.87250	.50377	.86384	.51877	.85491	.53361	.84573	45
16	.48888	.87235	.50403	.86369	.51902	.85476	.53386	.84557	44
17	.48913	.87221	.50428	.86354	.51927	.85461	.53411	.84542	43
18	.48938	.87207	.50453	.86340	.51952	.85446	.53435	.84526	42
19	.48964	.87193	.50478	.86325	.51977	.85431	.53460	.84511	41
20	.48989	.87178	.50503	.86310	.52002	.85416	.53484	.84495	40
21	.49014	.87164	.50528	.86295	.52026	.85401	.53509	.84480	39
22	.49040	.87150	.50553	.86281	.52051	.85385	.53534	.84464	38
23	.49065	.87136	.50578	.86266	.52076	.85370	.53558	.84448	37
24	.49090	.87121	.50603	.86251	.52101	.85355	.53583	.84433	36
25	.49116	.87107	.50628	.86237	.52126	.85340	.53607	.84417	35
26	.49141	.87093	.50654	.86222	.52151	.85325	.53632	.84402	34
27	.49166	.87079	.50679	.86207	.52175	.85310	.53656	.84386	33
28	.49192	.87064	.50704	.86192	.52200	.85294	.53681	.84370	32
29	.49217	.87050	.50729	.86178	.52225	.85279	.53705	.84355	31
30	.49242	.87036	.50754	.86163	.52250	.85264	.53730	.84339	30
31	.49268	.87021	.50779	.86148	.52275	.85249	.53754	.84324	29
32	.49293	.87007	.50804	.86133	.52299	.85234	.53779	.84308	28
33	.49318	.86993	.50829	.86119	.52324	.85218	.53804	.84292	27
34	.49344	.86978	.50854	.86104	.52349	.85203	.53828	.84277	26
35	.49369	.86964	.50879	.86089	.52374	.85188	.53853	.84261	25
36	.49394	.86949	.50904	.86074	.52399	.85173	.53877	.84245	24
37	.49419	.86935	.50929	.86059	.52423	.85157	.53902	.84230	23
38	.49445	.86921	.50954	.86045	.52448	.85142	.53926	.84214	22
39	.49470	.86906	.50979	.86030	.52473	.85127	.53951	.84198	21
40	.49495	.86892	.51004	.86015	.52498	.85112	.53975	.84182	20
41	.49521	.86878	.51029	.86000	.52522	.85096	.54000	.84167	19
42	.49546	.86863	.51054	.85985	.52547	.85081	.54024	.84151	18
43	.49571	.86849	.51079	.85970	.52572	.85066	.54049	.84135	17
44	.49596	.86834	.51104	.85956	.52597	.85051	.54073	.84120	16
45	.49622	.86820	.51129	.85941	.52621	.85035	.54097	.84104	15
46	.49647	.86805	.51154	.85926	.52646	.85020	.54122	.84088	14
47	.49672	.86791	.51179	.85911	52671	.85005	.54146	.84072	13
48	.49697	.86777	.51204	.85896	.52696	.84989	.54171	.84057	12
49	.49723	.86762	.51229	.85881	.52720	.84974	.54195	.84041	11
50	.49748	.86748	.51254	.85866	.52745	.84959	.54220	.84025	10
51	.49773	.86733	.51279	.85851	.52770	.84943	.54244	.84009	9
52	.49798	.86719	.51304	.85836	.52794	.84928	.54269	.83994	8
53	.49824	.86704	.51329	.85821	.52819	.84913	.54293	.83978	7
54	.49849	.86690	.51354	.85806	.52844	.84897	.54317	.83962	6
55	.49874	.86675	.51379	.85792	.52869	.84882	.54342	.83946	5
56	.49899	.86661	.51404	.85777	.52893	.84866	.54366	.83930	4
57	.49924	.86646	.51429	.85762	.52918	.84851	.54391	.83015	3
58	.49950	.86632	.51454	.85747	.52943	.84836	.54415	.83899	2
59	.49975	.86617	.51479	.85732	.52967	.84820	.54440	.83883	1
60	.50000	.86603	.51504	.85717	.52992	.84805	.54464	.83867	0
′	COSINE	SINE	COSINE	SINE	COSINE	SINE	COSINE	SINE	′
	60°		59°		58°		57°		

′	33°		34°		35°		36°		′
	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	
0	.54464	.83867	.55919	.82904	.57358	.81915	.58779	.80902	60
1	.54488	.83851	.55943	.82887	.57381	.81899	.58802	.80885	59
2	.54513	.83835	.55968	.82871	.57405	.81882	.58826	.80867	58
3	.54537	.83819	.55992	.82855	.57429	.81865	.58849	.80850	57
4	.54561	.83804	.56016	.82839	.57453	.81848	.58873	.80833	56
5	.54586	.83788	.56040	.82822	.57477	.81832	.58896	.80816	55
6	.54610	.83772	.56064	.82806	.57501	.81815	.58920	.80799	54
7	.54635	.83756	.56088	.82790	.57524	.81798	.58943	.80782	53
8	.54659	.83740	.56112	.82773	.57548	.81782	.58967	.80765	52
9	.54683	.83724	.56136	.82757	.57572	.81765	.58990	.80748	51
10	.54708	.83708	.56160	.82741	.57596	.81748	.59014	.80730	50
11	.54732	83692	.56184	.82724	.57619	.81731	.59037	.80713	49
12	.54756	.83676	.56208	.82708	.57643	.81714	.59061	.80696	48
13	.54781	.83660	.56232	.82692	.57667	.81698	.59084	.80679	47
14	.54805	.83645	.56256	.82675	.57691	.81681	.59108	.80662	46
15	.54829	.83629	.56280	.82659	.57715	.81664	.59131	.80644	45
16	.54854	.83613	.56305	.82643	.57738	.81647	.59154	.80627	44
17	.54878	.83597	.56329	.82626	.57762	.81631	.59178	.80610	43
18	.54902	.83581	.56353	.82610	.57786	.81614	.59201	.80593	42
19	.54927	.83565	.56377	.82593	.57810	.81597	.59225	.80576	41
20	.54951	.83549	.56401	.82577	.57833	.81580	.59248	.80558	40
21	.54975	.83533	.56425	.82561	.57857	.81563	.59272	.80541	39
22	.54999	.83517	.56449	.82544	.57881	.81546	.59295	.80524	38
23	.55024	.83501	.56473	.82528	.57904	.81530	.59318	.80507	37
24	.55048	.83485	.56497	.82511	.57928	.81513	.59342	.80489	36
25	.55072	.83469	.56521	.82495	.57952	.81496	.59365	.80472	35
26	.55097	.83453	.56545	.82478	.57976	.81479	.59389	.80455	34
27	.55121	.83437	.56569	.82462	.57999	.81462	.59412	.80438	33
28	.55145	.83421	.56593	.82446	.58023	.81445	.59436	.80420	32
29	.55169	.83405	.56617	.82429	.58047	.81428	.59459	.80403	31
30	.55194	.83389	.56641	.82413	.58070	.81412	.59482	.80386	30
31	.55218	.83373	.56665	.82396	.58094	.81395	.59506	.80368	29
32	.55242	.83356	.56689	.82380	.58118	.81378	.59529	.80351	28
33	.55266	.83340	.56713	.82363	.58141	.81361	.59552	.80334	27
34	.55291	.83324	.56736	.82347	.58165	.81344	.59576	.80316	26
35	.55315	.83308	.56760	.82330	.58189	.81327	.59599	.80299	25
36	.55339	.83292	.56784	.82314	.58212	.81310	.59622	.80282	24
37	.55363	.83276	.56808	.82297	.58236	.81293	.59646	.80264	23
38	55388	.83260	.56832	.82281	.58260	.81276	.59669	.80247	22
39	.55412	.83244	.56856	.82264	.58283	.81259	.59693	.80230	21
40	.55436	.83228	.56880	.82248	.58307	.81242	.59716	.80212	20
41	.55460	.83212	.56904	.82231	.58330	.81225	.59739	.80195	19
42	.55484	.83195	.56928	.82214	.58354	.81208	.59763	.80178	18
43	.55509	.83179	.56952	.82198	.58378	.81191	.59786	.80160	17
44	.55533	.83163	.56976	.82181	.58401	.81174	.59809	.80143	16
45	.55557	.83147	.57000	.82165	.58425	.81157	.59832	.80125	15
46	.55581	.83131	.57024	.82148	.58449	.81140	.59856	.80108	14
47	.55605	.83115	.57047	.82132	.58472	.81123	.59879	.80091	13
48	.55630	.83098	.57071	.82115	.58496	.81106	.59902	.80073	12
49	.55654	.83082	.57095	.82098	.58519	.81089	.59926	.80056	11
50	.55678	.83066	.57119	.82082	.58543	.81072	.59949	.80038	10
51	.55702	.83050	.57143	.82065	.58567	.81055	.59972	.80021	9
52	.55726	.83034	.57167	.82048	.58590	.81038	.59995	.80003	8
53	.55750	.83017	.57191	.82032	.58614	.81021	.60019	.79986	7
54	.55775	.83001	.57215	.82015	.58637	.81004	.60042	.79968	6
55	.55799	.82985	.57238	.81999	.58661	.80987	.60065	.79951	5
56	.55823	.82969	.57262	.81982	.58684	.80970	.60089	.79934	4
57	.55847	.82953	.57286	.81965	.58708	.80953	.60112	.79916	3
58	.55871	.82936	.57310	81949	.58731	.80936	.60135	.79899	2
59	.55895	.82920	.57334	.81932	.58755	.80919	.60158	.79881	1
60	.55919	.82904	.57358	.81915	.58779	.80902	.60182	.79864	0
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	56°		55°		54°		53°		

	37°		38°		39°		40°		
′	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	′
0	.60182	.79864	.61566	.78801	.62932	.77715	.64279	.76604	60
1	.60205	.79846	.61589	.78783	.62955	.77696	.64301	.76586	59
2	.60228	.79829	.61612	.78765	.62977	.77678	.64323	.76567	58
3	.60251	.79811	.61635	.78747	.63000	.77660	.64346	.76548	57
4	.60274	.79793	.61658	.78729	.63022	.77641	.64368	.76530	56
5	.60298	.79776	.61681	.78711	.63045	.77623	.64390	.76511	55
6	.60321	.79758	.61704	.78694	.63068	.77605	.64412	.76492	54
7	.60344	.79741	.61726	.78676	.63090	.77586	.64435	.76473	53
8	.60367	.79723	.61749	.78658	.63113	.77568	.64457	.76455	52
9	.60390	.79706	.61772	.78640	.63135	.77550	.64479	.76436	51
10	.60414	.79688	.61795	.78622	.63158	.77531	.64501	.76417	50
11	.60437	.79671	.61818	.78604	.63180	.77513	.64524	.76398	49
12	.60460	.79653	.61841	.78586	.63203	.77494	.64546	.76380	48
13	.60483	.79635	.61864	.78568	.63225	.77476	.64568	.76361	47
14	.60506	.79618	.61887	.78550	.63248	.77458	.64590	.76342	46
15	.60529	.79600	.61909	.78532	.63271	.77439	.64612	.76323	45
16	.60553	.79583	.61932	.78514	.63293	.77421	.64635	.76304	44
17	.60576	.79565	.61955	.78496	.63316	.77402	.64657	.76286	43
18	.60599	.79547	.61978	.78478	.63338	.77384	.64679	.76267	42
19	.60622	.79530	.62001	.78460	.63361	.77366	.64701	.76248	41
20	.60645	.79512	.62024	.78442	.63383	.77347	.64723	.76229	40
21	.60668	.79494	.62046	.78424	.63406	.77329	.64746	.76210	39
22	.60691	.79477	.62069	.78405	.63428	.77310	.64768	.76192	38
23	.60714	.79459	.62092	.78387	.63451	.77292	.64790	.76173	37
24	.60738	.79441	.62115	.78369	.63473	.77273	.64812	.76154	36
25	.60761	.79424	.62138	.78351	.63496	.77255	.64834	.76135	35
26	.60784	.79406	.62160	.78333	.63518	.77236	.64856	.76116	34
27	.60807	.79388	.62183	.78315	.63540	.77218	.64878	.76097	33
28	.60830	.79371	.62206	.78297	.63563	.77199	.64901	.76078	32
29	.60853	.79353	.62229	.78279	.63585	.77181	.64923	.76059	31
30	.60876	.79335	.62251	.78261	.63608	.77162	.64945	.76041	30
31	.60899	.79318	.62274	.78243	.63630	.77144	.64967	.76022	29
32	.60922	.79300	.62297	.78225	.63653	.77125	.64989	.76003	28
33	.60945	.79282	.62320	.78206	.63675	.77107	.65011	.75984	27
34	.60968	.79264	.62342	.78188	.63698	.77088	.65033	.75965	26
35	.60991	.79247	.62365	.78170	.63720	.77070	.65055	.75946	25
36	.61015	.79229	.62388	.78152	.63742	.77051	.65077	.75927	24
37	.61038	.79211	.62411	.78134	.63765	.77033	.65100	.75908	23
38	.61061	.79193	.62433	.78116	.63787	.77014	.65122	.75889	22
39	.61084	.79176	.62456	.78098	.63810	.76996	.65144	.75870	21
40	.61107	.79158	.62479	.78079	.63832	.76977	.65166	.75851	20
41	.61130	.79140	.62502	.78061	.63854	.76959	.65188	.75832	19
42	.61153	.79122	.62524	.78043	.63877	.76940	.65210	.75813	18
43	.61176	.79105	.62547	.78025	.63899	.76921	.65232	.75794	17
44	.61199	.79087	.62570	.78007	.63922	.76903	.65254	.75775	16
45	.61222	.79069	.62592	.77988	.63944	.76884	.65276	.75756	15
46	.61245	.79051	.62615	.77970	.63966	.76866	.65298	.75738	14
47	.61268	.79033	.62638	.77952	.63989	.76847	.65320	.75719	13
48	.61291	.79016	.62660	.77934	.64011	.76828	.65342	.75700	12
49	.61314	.78998	.62683	.77916	.64033	.76810	.65364	.75680	11
50	.61337	.78980	.62706	.77897	.64056	.76791	.65386	.75661	10
51	.61360	.78962	.62728	.77879	.64078	.76772	.65408	.75642	9
52	.61383	.78944	.62751	.77861	.64100	.76754	.65430	.75623	8
53	.61406	.78926	.62774	.77843	.64123	.76735	.65452	.75604	7
54	.61429	.78908	.62796	.77824	.64145	.76717	.65474	.75585	6
55	.61451	.78891	.62819	.77806	.64167	.76698	.65496	.75566	5
56	.61474	.78873	.62842	.77788	.64190	.76679	.65518	.75547	4
57	.61497	.78855	.62864	.77769	.64212	.76661	.65540	.75528	3
58	.61520	.78837	.62887	.77751	.64234	.76642	.65562	.75509	2
59	.61543	.78819	.62909	.77733	.64256	.76623	.65584	.75490	1
60	.61566	.78801	.62932	.77715	.64279	.76604	.65606	.75471	0
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	52°		51°		50°		49°		

	41°		42°		43°		44°		
′	SINE	COSINE	SINE	COSINE	SINE	COSINE	SINE	COSINE	′
0	.65606	.75471	.66913	.74314	.68200	.73135	.69466	.71934	60
1	.65628	.75452	.66935	.74295	.68221	.73116	.69487	.71914	59
2	.65650	.75433	.66956	.74276	.68242	.73096	.69508	.71894	58
3	.65672	.75414	.66978	.74256	.68264	.73076	.69529	.71873	57
4	.65694	.75395	.66999	.74237	.68285	.73056	.69549	.71853	56
5	.65716	.75375	.67021	.74217	.68306	.73036	.69570	.71833	55
6	.65738	.75356	.67043	.74198	.68327	.73016	.69591	.71813	54
7	.65759	.75337	.67064	.74178	.68349	.72996	.69612	.71792	53
8	.65781	.75318	.67086	.74159	.68370	.72976	.69633	.71772	52
9	.65803	.75299	.67107	.74139	.68391	.72957	.69654	.71752	51
10	.65825	.75280	.67129	.74120	.68412	.72937	.69675	.71732	50
11	.65847	.75261	.67151	.74100	.68434	.72917	.69696	.71711	49
12	.65869	.75241	.67172	.74080	.68455	.72897	.69717	.71691	48
13	.65891	.75222	.67194	.74061	.68476	.72877	.69737	.71671	47
14	.65913	.75203	.67215	.74041	.68497	.72857	.69758	.71650	46
15	.65935	.75184	.67237	.74022	.68518	.72837	.69779	.71630	45
16	.65956	.75165	.67258	.74002	.68539	.72817	.69800	.71610	44
17	.65978	.75146	.67280	.73983	.68561	.72797	.69821	.71590	43
18	.66000	.75126	.67301	.73963	.68582	.72777	.69842	.71569	42
19	.66022	.75107	.67323	.73944	.68603	.72757	.69862	.71549	41
20	.66044	.75088	.67344	.73924	.68624	.72737	.69883	.71529	40
21	.66066	.75069	.67366	.73904	.68645	.72717	.69904	.71508	39
22	.66088	.75050	.67387	.73885	.68666	.72697	.69925	.71488	38
23	.66109	.75030	.67409	.73865	.68688	.72677	.69946	.71468	37
24	.66131	.75011	.67430	.73846	.68709	.72657	.69966	.71447	36
25	.66153	.74992	.67452	.73826	.68730	.72637	.69987	.71427	35
26	.66175	.74973	.67473	.73806	.68751	.72617	.70008	.71407	34
27	.66197	.74953	.67495	.73787	.68772	.72597	.70029	.71386	33
28	.66218	.74934	.67516	.73767	.68793	.72577	.70049	.71366	32
29	.66240	.74915	.67538	.73747	.68814	.72557	.70070	.71345	31
30	.66262	.74896	.67559	.73728	.68835	.72537	.70091	.71325	30
31	.66284	.74876	.67580	.73708	.68857	.72517	.70112	.71305	29
32	.66306	.74857	.67602	.73688	.68878	.72497	.70132	.71284	28
33	.66327	.74838	.67623	.73669	.68809	.72477	.70153	.71264	27
34	.66349	.74818	.67645	.73649	.68920	.72457	.70174	.71243	26
35	.66371	.74799	.67666	.73629	.68941	.72437	.70195	.71223	25
36	.66393	.74780	.67688	.73610	.68962	.72417	.70215	.71203	24
37	.66414	.74760	.67709	.73590	.68983	.72397	.70236	.71182	23
38	.66436	.74741	.67730	.73570	.69004	.72377	.70257	.71162	22
39	.66458	.74722	.67752	.73551	.69025	.72357	.70277	.71141	21
40	.66480	.74703	.67773	.73531	.69046	.72337	.70298	.71121	20
41	.66501	.74683	.67795	.73511	.69067	.72317	.70319	.71100	19
42	.66523	.74664	.67816	.73491	.69088	.72297	.70339	.71080	18
43	.66545	.74644	.67837	.73472	.69109	.72277	.70360	.71059	17
44	.66566	.74625	.67859	.73452	.69130	.72257	.70381	.71039	16
45	.66588	.74606	.67880	.73432	.69151	.72236	.70401	.71019	15
46	.66610	.74586	.67901	.73413	.69172	.72216	.70422	.70998	14
47	.66632	.74567	.67923	.73393	.69193	.72196	.70443	.70978	13
48	.66653	.74548	.67944	.73373	.69214	.72176	.70463	.70957	12
49	.66675	.74528	.67965	.73353	.69235	.72156	.70484	.70937	11
50	.66697	.74509	.67987	.73333	.69256	.72136	.70505	.70916	10
51	.66718	.74489	.68008	.73314	.69277	.72116	.70525	.70896	9
52	.66740	.74470	.68029	.73294	.69298	.72095	.70546	.70875	8
53	.66762	.74451	.68051	.73274	.69319	.72075	.70567	.70855	7
54	.66783	.74431	.68072	.73254	.69340	.72055	.70587	.70834	6
55	.66805	.74412	.68093	.73234	.69361	.72035	.70608	.70813	5
56	.66827	.74302	.68115	.73215	.69382	.72015	.70628	.70793	4
57	.66848	.74373	.68136	.73195	.69403	.71995	.70649	.70772	3
58	.66870	.74353	.68157	.73175	.69424	.71974	.70670	.70752	2
59	.56891	.74334	.68179	.73155	.69445	.71954	.70690	.70731	1
60	.66913	.74314	.68200	.73135	.69466	.71934	.70711	.70711	0
′	COSINE	SINE	COSINE	SINE	COSINE	SINE	COSINE	SINE	′
	48°		47°		46°		45°		

	0°		1°		2°		3°		
′	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	′
0	1	Infinite.	1.0001	57.299	1.0006	28.654	1.0014	19.107	60
1	1	3437.70	1.0001	56.359	1.0006	28.417	1.0014	19.002	59
2	1	1718.90	1.0002	55.450	1.0006	28.184	1.0014	18.897	58
3	1	1145.90	1.0002	54.570	1.0006	27.955	1.0014	18.794	57
4	1	859.44	1.0002	53.718	1.0006	27.730	1.0014	18.692	56
5	1	687.55	1.0002	52.891	1.0007	27.508	1.0014	18.591	55
6	1	572.96	1.0002	52.090	1.0007	27.290	1.0015	18.491	54
7	1	491.11	1.0002	51.313	1.0007	27.075	1.0015	18.393	53
8	1	429.72	1.0002	50.558	1.0007	26.864	1.0015	18.295	52
9	1	381.97	1.0002	49.826	1.0007	26.655	1.0015	18.198	51
10	1	343.77	1.0002	49.114	1.0007	26.450	1.0015	18.103	50
11	1	312.52	1.0002	48.422	1.0007	26.249	1.0015	18.008	49
12	1	286.48	1.0002	47.750	1.0007	26.050	1.0016	17.914	48
13	1	264.44	1.0002	47.096	1.0007	25.854	1.0016	17.821	47
14	1	245.55	1.0002	46.460	1.0008	25.661	1.0016	17.730	46
15	1	229.18	1.0002	45.840	1.0008	25.471	1.0016	17.639	45
16	1	214.86	1.0002	45.237	1.0008	25.284	1.0016	17.549	44
17	1	202.22	1.0002	44.650	1.0008	25.100	1.0016	17.460	43
18	1	190.99	1.0002	44.077	1.0008	24.918	1.0017	17.372	42
19	1	180.73	1.0003	43.520	1.0008	24.739	1.0017	17.285	41
20	1	171.89	1.0003	42.976	1.0008	24.562	1.0017	17.198	40
21	1	163.70	1.0003	42.445	1.0008	24.358	1.0017	17.113	39
22	1	156.26	1.0003	41.928	1.0008	24.216	1.0017	17.028	38
23	1	149.47	1.0003	41.423	1 0009	24.047	1.0017	16.944	37
24	1	143.24	1.0003	40.930	1.0009	23.880	1.0018	16.861	36
25	1	137.51	1.0003	40.448	1.0009	23.716	1.0018	16.779	35
26	1	132.22	1.0003	39.978	1.0009	23.553	1.0018	16.698	34
27	1	127.32	1.0003	39.518	1.0009	23.393	1.0018	16.617	33
28	1	122.78	1.0003	39.069	1.0009	23.235	1.0018	16.538	32
29	1	118.54	1.0003	38.631	1.0009	23.079	1.0018	16.459	31
30	1	114.59	1.0003	38.201	1.0009	22.925	1.0019	16.380	30
31	1	110.90	1.0003	37.782	1.0010	22.774	1.0019	16.303	29
32	1	107.43	1.0003	37.371	1.0010	22.624	1.0019	16.226	28
33	1	104.17	1.0004	36.969	1.0010	22.476	1.0019	16.150	27
34	1	101.11	1.0004	36.576	1.0010	22.330	1.0019	16.075	26
35	1	98.223	1.0004	36.191	1.0010	22.186	1.0019	16.000	25
36	1	95.495	1.0004	35.814	1.0010	22.044	1.0020	15.926	24
37	1	92.914	1.0004	35.445	1.0010	21.904	1.0020	15.853	23
38	1.0001	92.469	1.0004	35.084	1.0010	21.765	1.0020	15.780	22
39	1.0001	88.149	1.0004	34.729	1.0011	21.629	1.0020	15.708	21
40	1.0001	85.946	1.0004	34.382	1.0011	21.494	1.0020	15.637	20
41	1.0001	83.849	1.0004	34.042	1.0011	21.360	1.0021	15.566	19
42	1.0001	81.853	1.0004	33.708	1.0011	21.228	1.0021	15.496	18
43	1.0001	79.950	1.0004	33.381	1.0011	21.098	1.0021	15.427	17
44	1.0001	78.133	1.0004	33.060	1.0011	20.970	1.0021	15.358	16
45	1.0001	76.396	1.0005	32.745	1.0011	20.843	1.0021	15.290	15
46	1.0001	74.736	1.0005	32.437	1.0012	20.717	1.0022	15.222	14
47	1.0001	73.146	1.0005	32.134	1.0012	20.593	1.0022	15.155	13
48	1.0001	71.622	1.0005	31.836	1.0012	20.471	1.0022	15.089	12
49	1.0001	70.160	1.0005	31.544	1.0012	20.350	1.0022	15.023	11
50	1.0001	68.757	1.0005	31.257	1.0012	20.230	1.0022	14.958	10
51	1.0001	67.409	1.0005	30.976	1.0012	20.112	1.0023	14.893	9
52	1.0001	66.113	1.0005	30.699	1.0012	19.995	1.0023	14.829	8
53	1.0001	64.866	1.0005	30.428	1.0013	19.880	1.0023	14.765	7
54	1.0001	63.664	1.0005	30.161	1.0013	19.766	1.0023	14.702	6
55	1.0001	62.507	1.0005	29.899	1.0013	19.653	1.0023	14.640	5
56	1.0001	61.391	1.0006	29.641	1.0013	19.541	1.0024	14.578	4
57	1.0001	61.314	1.0006	29.388	1.0013	19.431	1.0024	14.517	3
58	1.0001	59.274	1.0006	29.139	1.0013	19.322	1.0024	14.456	2
59	1.0001	58.270	1.0006	28.894	1.0013	19.214	1.0024	14.395	1
60	1.0001	57.299	1.0006	28.654	1.0014	19.107	1.0024	14.335	0
′	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	
	89°		88°		87°		86°		

	4°		5°		6°		7°		
′	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec	Sec.	Co-sec.	′
0	1.0024	14.335	1.0038	11.474	1.0055	9.5668	1.0075	8.2055	60
1	1.0025	14.276	1.0038	11.436	1.0055	9.5404	1.0075	8.1861	59
2	1.0025	14.217	1.0039	11.398	1.0056	9.5141	1.0076	8.1668	58
3	1.0025	14.159	1.0039	11.360	1.0056	9.4880	1.0076	8.1476	57
4	1.0025	14.101	1.0039	11.323	1.0056	9.4620	1.0076	8.1285	56
5	1.0025	14.043	1.0039	11.286	1.0057	9.4362	1.0077	8.1094	55
6	1.0026	13.986	1.0040	11.249	1.0057	9.4105	1.0077	8.0905	54
7	1.0026	13.930	1.0040	11.213	1.0057	9.3850	1.0078	8.0717	53
8	1.0026	13.874	1.0040	11.176	1.0057	9.3596	1.0078	8.0529	52
9	1.0026	13.818	1.0040	11.140	1.0058	9.3343	1.0078	8 0342	51
10	1.0026	13.763	1.0041	11.104	1.0058	9.3092	1.0079	8.0156	50
11	1.0027	13.708	1.0041	11.069	1.0058	9.2842	1.0079	7.9971	49
12	1.0027	13.654	1.0041	11.033	1.0059	9.2593	1.0079	7.9787	48
13	1.0027	13.600	1.0041	10.988	1.0059	9.2346	1.0080	7.9604	47
14	1.0027	13.547	1.0042	10.963	1.0059	9.2100	1.0080	7.9421	46
15	1.0027	13.494	1.0042	10.929	1.0060	9.1855	1.0080	7.9240	45
16	1.0028	13.441	1.0042	10.894	1.0060	9.1612	1.0081	7.9059	44
17	1.0028	13.389	1.0043	10.860	1.0060	9.1370	1.0081	7.8879	43
18	1.0028	13.337	1.0043	10.826	1.0061	9.1129	1.0082	7.8700	42
19	1.0028	13.286	1.0043	10.792	1.0061	9.0890	1.0082	7.8522	41
20	1.0029	13.235	1.0043	10.758	1.0061	9.0651	1.0082	7.8344	40
21	1.0029	13.184	1.0044	10.725	1.0062	9.0414	1.0083	7.8168	39
22	1.0029	13.134	1.0044	10.692	1 0062	9.0179	1.0083	7.7992	38
23	1.0029	13.084	1.0044	10.659	1.0062	8.9944	1.0084	7.7817	37
24	1.0029	13.034	1.0044	10.626	1.0063	8.9711	1.0084	7.7642	36
25	1.0030	12.985	1.0045	10.593	1.0063	8.9479	1.0084	7.7469	35
26	1.0030	12.937	1.0045	10.561	1.0063	8.9248	1.0085	7.7296	34
27	1.0030	12.888	1.0045	10.529	1.0064	8.9018	1.0085	7.7124	33
28	1.0030	12.840	1.0046	10.497	1.0064	8.8790	1.0085	7.6953	32
29	1.0031	12.793	1.0046	10.465	1.0064	8.8563	1.0086	7.6783	31
30	1.0031	12.745	1.0046	10.433	1.0065	8.8337	1.0086	7.6613	30
31	1.0031	12.698	1.0046	10.402	1.0065	8.8112	1.0087	7.6444	29
32	1.0031	12.652	1.0047	10.371	1.0065	8.7888	1.0087	7.6276	28
33	1.0032	12.606	1.0047	10.340	1.0066	8.7665	1.0087	7.6108	27
34	1.0032	12.560	1.0047	10.309	1.0066	8.7444	1.0088	7.5942	26
35	1.0032	12.514	1.0048	10.278	1.0066	8.7223	1.0088	7.5776	25
35	1.0032	12.469	1.0048	10.248	1.0067	8.7004	1.0089	7.5611	24
37	1.0032	12.424	1.0048	10.217	1.0067	8.6786	1.0089	7.5446	23
38	1.0033	12.379	1.0048	10.187	1.0067	8.6569	1.0089	7.5282	22
39	1.0033	12.335	1.0049	10.157	1.0068	8.6353	1.0090	7.5119	21
40	1.0033	12.291	1.0049	10.127	1.0068	8.6138	1'0090	7.4957	20
41	1.0033	12.248	1.0049	10.098	1.0068	8.5924	1.0090	7.4795	19
42	1.0034	12.204	1.0050	10.068	1.0069	8.5711	1.0091	7.4634	18
43	1.0034	12.161	1.0050	10.039	1.0069	8.5499	1.0091	7.4474	17
44	1.0034	12.118	1.0050	10.010	1.0069	8.5289	1.0092	7.4315	16
45	1.0034	12.076	1.0050	9.9812	1.0070	8.5079	1.0092	7.4156	15
46	1.0035	12.034	1.0051	9.9525	1.0070	8.4871	1.0092	7.3998	14
47	1.0035	11.992	1.0051	9 9239	1.0070	8.4663	1.0093	7.3840	13
48	1.0035	11.950	1.0051	9.8055	1.0071	8.4457	1.0093	7.3683	12
49	1.0035	11.909	1.0052	9.8672	1.0071	8.4251	1.0094	7.3527	11
50	1.0036	11.868	1.0052	9.8391	1.0071	8.4046	1.0094	7.3372	10
51	1.0036	11.828	1.0052	9.8112	1.0072	8.3843	1.0094	7.3217	9
52	1.0036	11.787	1.0053	9.7834	1.0072	8.3640	1.0095	7.3063	8
53	1.0036	11.747	1.0053	9.7558	1.0073	8.3439	1.0095	7.2909	7
54	1.0037	11.707	1.0053	9.7283	1.0073	8.3238	1.0096	7.2757	6
55	1.0037	11.668	1.0053	9.7010	1.0073	8.3039	1.0096	7.2604	5
56	1.0037	11.628	1.0054	9.6739	1.0074	8.2840	1.0097	7.2453	4
57	1.0037	11.589	1.0054	9.6469	1.0074	8.2642	1.0097	7.2302	3
58	1.0038	11.550	1.0054	9.6200	1.0074	8.2446	1.0097	7.2152	2
59	1.0038	11.512	1.0055	9.5933	1.0075	8.2250	1.0098	7.2002	1
60	1.0038	11.474	1.0055	9.5668	1.0075	8.2055	1.0098	7.1853	0
′	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	′
	85°		84°		83°		82°		

′	8°		9°		10°		11°		′
′	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	′
0	1.0098	7.1853	1.0125	6.3924	1.0154	5.7588	1.0187	5.2408	60
1	1.0099	7.1704	1.0125	6.3807	1.0155	5.7493	1.0188	5.2330	59
2	1.0099	7.1557	1.0125	6.3690	1.0155	5.7398	1.0188	5.2252	58
3	1.0099	7.1409	1.0126	6.3574	1.0156	5.7304	1.0189	5.2174	57
4	1.0100	7.1263	1.0126	6.3458	1.0156	5.7210	1.0189	5.2097	56
5	1.0100	7.1117	1.0127	6.3343	1.0157	5.7117	1.0190	5.2019	55
6	1.0101	7.0972	1.0127	6.3228	1.0157	5.7023	1.0191	5.1942	54
7	1.0101	7.0827	1.0128	6.3113	1.0158	5.6930	1.0191	5.1865	53
8	1.0102	7.0683	1.0128	6.2999	1.0158	5.6838	1.0192	5.1788	52
9	1.0102	7.0539	1.0129	6.2885	1.0159	5.6745	1.0192	5.1712	51
10	1.0102	7.0396	1.0129	6.2772	1.0159	5.6653	1.0193	5.1636	50
11	1.0103	7.0254	1.0130	6.2659	1.0160	5.6561	1.0193	5.1560	49
12	1.0103	7.0112	1.0130	6.2546	1.0160	5.6470	1.0194	5.1484	48
13	1.0104	6.9971	1.0131	6.2434	1.0161	5.6379	1.0195	5.1409	47
14	1.0104	6.9830	1.0131	6.2322	1.0162	5.6288	1.0195	5.1333	46
15	1.0104	6.9690	1.0132	6.2211	1.0162	5.6197	1.0196	5.1258	45
16	1.0105	6.9550	1.0132	6.2100	1.0163	5.6107	1.0196	5.1183	44
17	1.0105	6.9411	1.0133	6.1990	1.0163	5.6017	1.0197	5.1109	43
18	1.0106	6.9273	1.0133	6.1880	1.0164	5.5928	1.0198	5.1034	42
19	1.0106	6.9135	1.0134	6.1770	1.0164	5.5838	1.0198	5.0960	41
20	1.0107	6.8998	1.0134	6.1661	1.0165	5.5749	1.0199	5.0886	40
21	1.0107	6.8861	1.0135	6.1552	1.0165	5.5660	1.0199	5.0812	39
22	1.0107	6.8725	1.0135	6.1443	1.0166	5.5572	1.0200	5.0739	38
23	1.0108	6.8589	1.0136	6.1335	1.0166	5.5484	1.0201	5.0666	37
24	1.0108	6.8454	1.0136	6.1227	1.0167	5.5396	1.0201	5.0593	36
25	1.0109	6.8320	1.0136	6.1120	1.0167	5.5308	1.0202	5.0520	35
26	1.0109	6.8185	1.0137	6.1013	1.0168	5.5221	1.0202	5.0447	34
27	1.0110	6.8052	1.0137	6.0906	1.0169	5.5134	1.0203	5.0375	33
28	1.0110	6.7919	1.0138	6.0800	1.0169	5.5047	1.0204	5.0302	32
29	1.0111	6.7787	1.0138	6.0694	1.0170	5.4960	1.0204	5.0230	31
30	1.0111	6.7655	1.0139	6.0588	1.0170	5.4874	1.0205	5.0158	30
31	1.0111	6.7523	1.0139	6.0483	1.0171	5.4788	1.0205	5.0087	29
32	1.0112	6.7392	1.0140	6.0379	1.0171	5.4702	1.0206	5.0015	28
33	1.0112	6.7262	1.0140	6.0274	1.0172	5.4617	1.0207	4.9944	27
34	1.0113	6.7132	1.0141	6.0170	1.0172	5.4532	1.0207	4.9873	26
35	1.0113	6.7003	1.0141	6.0066	1.0173	5.4447	1.0208	4.9802	25
36	1.0114	6.6874	1.0142	5.9963	1.0174	5.4362	1.0208	4.9732	24
37	1.0114	6.6745	1.0142	5.9860	1.0174	5.4278	1.0209	4.9661	23
38	1.0115	6.6617	1.0143	5.9758	1.0175	5.4194	1.0210	4.9591	22
39	1.0115	6.6490	1.0143	5.9655	1.0175	5.4110	1.0210	4.9521	21
40	1.0115	6.6363	1.0144	5.9554	1.0176	5.4026	1.0211	4.9452	20
41	1.0116	6.6237	1.0144	5.9452	1.0176	5.3943	1.0211	4.9382	19
42	1.0116	6.6111	1.0145	5.9351	1.0177	5.3860	1.0212	4.9313	18
43	1.0117	6.5985	1.0145	5.9250	1.0177	5.3777	1.0213	4.9243	17
44	1.0117	6.5860	1.0146	5.9150	1.0178	5.3695	1.0213	4.9175	16
45	1.0118	6.5736	1.0146	5.9049	1.0179	5.3612	1.0214	4.9106	15
46	1.0118	6.5612	1.0147	5.8950	1.0179	5.3530	1.0215	4.9037	14
47	1.0119	6.5488	1.0147	5.8850	1.0180	5.3449	1.0215	4.8969	13
48	1.0119	6.5365	1.0148	5.8751	1.0180	5.3367	1.0216	4.8901	12
49	1.0119	6.5243	1.0148	5.8652	1.0181	5.3286	1.0216	4.8833	11
50	1.0120	6.5121	1.0149	5.8554	1.0181	5.3205	1.0217	4.8765	10
51	1.0120	6.4999	1.0150	5.8456	1.0182	5.3124	1.0218	4.8697	9
52	1.0121	6.4878	1.0150	5.8358	1.0182	5.3044	1.0218	4.8630	8
53	1.0121	6.4757	1.0151	5.8261	1.0183	5.2963	1.0219	4.8563	7
54	1.0122	6.4637	1.0151	5.8163	1.0184	5.2883	1.0220	4.8496	6
55	1.0122	6.4517	1.0152	5.8067	1.0184	5.2803	1.0220	4.8429	5
56	1.0123	6.4398	1.0152	5.7970	1.0185	5.2724	1.0221	4.8362	4
57	1.0123	6.4279	1.0153	5.7874	1.0185	5.2645	1.0221	4.8296	3
58	1.0124	6.4160	1.0153	5.7778	1.0186	5.2566	1.0222	4.8229	2
59	1.0124	6.4042	1.0154	5.7683	1.0186	5.2487	1.0223	4.8163	1
60	1.0125	6.3924	1.0154	5.7588	1.0187	5.2408	1.0223	4.8097	0
′	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	′
	81°		80°		79°		78°		

	12°		13°		14°		15°		
′	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	′
0	1.0223	4.8097	1.0263	4.4454	1.0306	4.1336	1.0353	3.8637	60
1	1.0224	4.8032	1.0264	4.4398	1.0307	4.1287	1.0353	3.8595	59
2	1.0225	4.7966	1.0264	4.4342	1.0308	4.1239	1.0354	3.8553	58
3	1.0225	4.7901	1.0265	4.4287	1.0308	4.1191	1.0355	3.8512	57
4	1.0226	4.7835	1.0266	4.4231	1.0309	4.1144	1.0356	3.8470	56
5	1.0226	4.7770	1.0266	4.4176	1.0310	4.1096	1.0357	3.8428	55
6	1.0227	4.7706	1.0267	4.4121	1.0311	4.1048	1.0358	3.8387	54
7	1.0228	4.7641	1.0268	4.4065	1.0311	4.1001	1.0358	3.8346	53
8	1.0228	4.7576	1.0268	4.4011	1.0312	4.0953	1.0359	3.8304	52
9	1.0229	4.7512	1.0269	4.3956	1.0313	4.0906	1.0360	3.8263	51
10	1.0230	4.7448	1.0270	4.3910	1.0314	4.0859	1.0361	3.8222	50
11	1.0230	4.7384	1.0271	4.3847	1.0314	4.0812	1.0362	3.8181	49
12	1.0231	4.7320	1.0271	4.3792	1.0315	4.0765	1.0362	3.8140	48
13	1.0232	4.7257	1.0272	4.3738	1.0316	4.0718	1.0363	3.8100	47
14	1.0232	4.7193	1.0273	4.3684	1.0317	4.0672	1.0364	3.8059	46
15	1.0233	4.7130	1.0273	4.3630	1.0317	4.0625	1.0365	3.8018	45
16	1.0234	4.7067	1.0274	4.3576	1.0318	4.0579	1.0366	3.7978	44
17	1.0234	4.7004	1.0275	4.3522	1.0319	4.0532	1.0367	3.7937	43
18	1.0235	4.6942	1.0276	4.3469	1.0320	4.0486	1.0367	3.7897	42
19	1.0235	4.6879	1.0276	4.3415	1.0320	4.0440	1.0368	3.7857	41
20	1.0236	4.6817	1.0277	4.3362	1.0321	4.0394	1.0369	3.7816	40
21	1.0237	4.6754	1.0278	4.3309	1.0322	4.0348	1.0370	3.7776	39
22	1.0237	4.6692	1.0278	4.3256	1.0323	4.0302	1.0371	3.7736	38
23	1.0238	4.6631	1.0279	4.3203	1.0323	4.0256	1.0371	3.7697	37
24	1.0239	4.6569	1.0280	4.3150	1.0324	4.0211	1.0372	3.7657	36
25	1.0239	4.6507	1.0280	4.3098	1.0325	4.0165	1.0373	3.7617	35
26	1.0240	4.6446	1.0281	4.3045	1.0326	4.0120	1.0374	3.7577	34
27	1.0241	4.6385	1.0282	4.2993	1.0327	4.0074	1.0375	3.7538	33
28	1.0241	4.6324	1.0283	4.2941	1.0327	4.0029	1.0376	3.7498	32
29	1.0242	4.6263	1.0283	4.2888	1.0328	3.9984	1.0376	3.7459	31
30	1.0243	4.6202	1.0284	4.2836	1.0329	3.9939	1.0377	3.7420	30
31	1.0243	4.6142	1.0285	4.2785	1.0330	3.9894	1.0378	3.7380	29
32	1.0244	4.6081	1.0285	4.2733	1.0330	3.9850	1.0379	3.7341	28
33	1.0245	4.6021	1.0286	4.2681	1.0331	3.9805	1.0380	3.7302	27
34	1.0245	4.5961	1.0287	4.2630	1.0332	3.9760	1.0381	3.7263	26
35	1.0246	4.5901	1.0288	4.2579	1.0333	3.9716	1.0382	3.7224	25
36	1.0247	4.5841	1.0288	4.2527	1.0334	3.9672	1.0382	3.7186	24
37	1.0247	4.5782	1.0289	4.2476	1.0334	3.9627	1.0383	3 7147	23
38	1.0248	4.5722	1.0290	4.2425	1.0335	3.9583	1.0384	3.7108	22
39	1.0249	4.5663	1.0291	4.2375	1.0336	3.9539	1.0385	3.7070	21
40	1.0249	4.5604	1.0291	4.2324	1.0337	3.9495	1.0386	3.7031	20
41	1.0250	4.5545	1.0202	4.2273	1.0338	3.9451	1.0387	3.6993	19
42	1.0251	4.5486	1.0293	4.2223	1.0338	3.9408	1.0387	3.6955	18
43	1.0251	4.5428	1.0293	4.2173	1.0339	3.9364	1.0388	3.6917	17
44	1.0252	4.5369	1.0294	4.2122	1.0340	3.9320	1.0389	3.6878	16
45	1.0253	4.5311	1.0295	4.2072	1.0341	3.9277	1.0390	3.6840	15
46	1.0253	4 5253	1.0296	4.2022	1.0341	3.9234	1.0391	3.6802	14
47	1.0254	4.5195	1.0296	4.1972	1.0342	3.9199	1.0392	3.6765	13
48	1.0255	4.5137	1.0297	4.1923	1.0343	3.9147	1.0393	3.6727	12
49	1.0255	4.5079	1.0298	4.1873	1.0344	3.9104	1.0393	3.6689	11
50	1.0256	4.5021	1.0299	4.1824	1.0345	3.9061	1.0394	3.6651	10
51	1.0257	4.4964	1.0299	4.1774	1.0345	3.9018	1.0395	3.6614	9
52	1.0257	4.4907	1.0300	4.1725	1.0346	3.8976	1.0396	3.6576	8
53	1.0258	4.4850	1.0301	4.1676	1.0347	3.8033	1.0397	3.6539	7
54	1.0259	4.4793	1.0302	4.1627	1.0348	3.8990	1.0398	3.6502	6
55	1.0260	4.4736	1.0302	4.1578	1.0349	3.8848	1.0399	3.6464	5
56	1.0260	4.4679	1.0303	4.1529	1.0349	3.8805	1.0399	3.6427	4
57	1.0261	4.4623	1.0304	4.1481	1.0350	3.8763	1.0400	3.6390	3
58	1.0262	4.4566	1.0305	4.1432	1.0351	3.8721	1.0401	3.0353	2
59	1.0262	4.4510	1.0305	4.1384	1.0352	3.8679	1.0402	3.6316	1
60	1.0263	4.4454	1.0306	4.1336	1.0353	3.8637	1.0403	3.6279	0
′	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	′
	77°		76°		75°		74°		

′	16°		17°		18°		19°		′
	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	
0	1.0403	3.6279	1.0457	3.4203	1.0515	3.2361	1.0576	3.0715	60
1	1.0404	3.6243	1.0458	3.4170	1.0516	3.2332	1.0577	3.0690	59
2	1.0405	3.6206	1.0459	3.4138	1.0517	3.2303	1.0578	3.0664	58
3	1.0406	3.6169	1.0460	3.4106	1.0518	3.2274	1.0579	3.0638	57
4	1.0406	3.6133	1.0461	3.4073	1.0519	3.2245	1.0580	3.0612	56
5	1.0407	3.6096	1.0461	3.4041	1.0520	3.2216	1.0581	3.0586	55
6	1.0408	3.6060	1.0462	3.4009	1.0521	3.2188	1.0582	3.0561	54
7	1.0409	3.6024	1.0463	3.3977	1.0522	3.2159	1.0584	3.0535	53
8	1.0410	3.5987	1.0464	3.3945	1.0523	3.2131	1.0585	3.0509	52
9	1.0411	3.5951	1.0465	3.3913	1.0524	3.2102	1.0586	3.0484	51
10	1.0412	3.5915	1.0466	3.3881	1.0525	3.2074	1.0587	3.0458	50
11	1.0413	3.5879	1.0467	3.3849	1.0526	3.2045	1.0588	3.0433	49
12	1.0413	3.5843	1.0468	3.3817	1.0527	3.2017	1.0589	3.0407	48
13	1.0414	3.5807	1.0469	3.3785	1.0528	3.1989	1.0590	3.0382	47
14	1.0415	3.5772	1.0470	3.3754	1.0529	3.1960	1.0591	3.0357	46
15	1.0416	3.5736	1.0471	3.3722	1.0530	3.1932	1.0592	3.0331	45
16	1.0417	3.5700	1.0472	3.3690	1.0531	3.1904	1.0593	3.0306	44
17	1.0418	3.5665	1.0473	3.3659	1.0532	3.1876	1.0594	3.0281	43
18	1.0419	3.5629	1.0474	3.3627	1.0533	3.1848	1.0595	3.0256	42
19	1.0420	3.5594	1.0475	3.3596	1.0534	3.1820	1.0596	3.0231	41
20	1.0420	3.5559	1.0476	3.3565	1.0535	3.1792	1.0598	3.0206	40
21	1.0421	3.5523	1.0477	3.3534	1.0536	3.1764	1.0599	3.0181	39
22	1.0422	3.5488	1.0478	3.3502	1.0537	3.1736	1.0600	3.0156	38
23	1.0423	3.5453	1.0478	3.3471	1.0538	3.1708	1.0601	3.0131	37
24	1.0424	3.5418	1.0479	3.3440	1.0539	3.1681	1.0602	3.0106	36
25	1.0425	3.5383	1.0480	3.3409	1.0540	3.1653	1.0603	3.0081	35
26	1.0426	3.5348	1.0481	3.3378	1.0541	3.1625	1.0604	3.0056	34
27	1.0427	3.5313	1.0482	3.3347	1.0542	3.1598	1.0605	3.0031	33
28	1.0428	3.5279	1.0483	3.3316	1.0543	3.1570	1.0606	3.0007	32
29	1.0428	3.5244	1.0484	3.3286	1.0544	3.1543	1.0607	2.9982	31
30	1.0429	3.5209	1.0485	3.3255	1.0545	3.1515	1.0608	2.9957	30
31	1.0430	3.5175	1.0486	3.3224	1.0546	3.1488	1.0609	2.9933	29
32	1.0431	3.5140	1.0487	3.3194	1.0547	3.1461	1.0611	2.9908	28
33	1.0432	3.5106	1.0488	3.3163	1.0548	3.1433	1.0612	2.9884	27
34	1.0433	3.5072	1.0489	3.3133	1.0549	3.1406	1.0613	2.9859	26
35	1.0434	3.5037	1.0490	3.3102	1.0550	3.1379	1.0614	2.9835	25
36	1.0435	3.5003	1.0491	3.3072	1.0551	3.1352	1.0615	2.9810	24
37	1.0436	3.4969	1.0492	3.3042	1.0552	3.1325	1.0616	2.9786	23
38	1.0437	3.4935	1.0493	3.3011	1.0553	3.1298	1.0617	2.9762	22
39	1.0438	3.4901	1.0494	3.2981	1.0554	3.1271	1.0618	2.9738	21
40	1.0438	3.4867	1.0495	3.2951	1.0555	3.1244	1.0619	2.9713	20
41	1.0439	3.4833	1.0496	3.2921	1.0556	3.1217	1.0620	2.9689	19
42	1.0440	3.4799	1.0497	3.2891	1.0557	3.1190	1.0622	2.9665	18
43	1.0441	3.4766	1.0498	3.2861	1.0558	3.1163	1.0623	2.9641	17
44	1.0442	3.4732	1.0499	3.2831	1.0559	3.1137	1.0624	2.9617	16
45	1.0443	3.4698	1.0500	3.2801	1.0560	3.1110	1.0625	2.9593	15
46	1.0444	3.4665	1.0501	3.2772	1.0561	3.1083	1.0626	2.9569	14
47	1.0445	3.4632	1.0502	3.2742	1.0562	3.1057	1.0627	2.9545	13
48	1.0446	3.4598	1.0503	3.2712	1.0563	3.1030	1.0628	2.9521	12
49	1.0447	3.4565	1.0504	3.2683	1.0565	3.1004	1.0629	2.9497	11
50	1.0448	3.4532	1.0505	3.2653	1.0566	3.0977	1.0630	2.9474	10
51	1.0448	3.4498	1.0506	3.2624	1.0567	3.0951	1.0632	2.9450	9
52	1.0449	3.4465	1.0507	3.2594	1.0568	3.0925	1.0633	2.9426	8
53	1.0450	3.4432	1.0508	3.2565	1.0569	3.0898	1.0634	2.9402	7
54	1.0451	3.4399	1.0509	3.2535	1.0570	3.0872	1.0635	2.9379	6
55	1.0452	3.4366	1.0510	3.2506	1.0571	3.0846	1.0636	2.9355	5
56	1.0453	3.4334	1.0511	3.2477	1.0572	3.0820	1.0637	2.9332	4
57	1.0454	3.4301	1.0512	3.2448	1.0573	3.0793	1.0638	2.9308	3
58	1.0455	3.4268	1.0513	3.2419	1.0574	3.0767	1.0639	2.9285	2
59	1.0456	3.4236	1.0514	3.2390	1.0575	3.0741	1.0641	2.9261	1
60	1.0457	3.4203	1.0515	3.2361	1.0576	3.0715	1.0642	2.9238	0
′	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	′
	73°		72°		71°		70°		

′	20°		21°		22°		23°		′
′	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	′
0	1.0642	2.9238	1.0711	2.7904	1.0785	2.6695	1.0864	2.5593	60
1	1.0643	2.9215	1.0713	2.7883	1.0787	2.6675	1.0865	2.5575	59
2	1.0644	2.9191	1.0714	2.7862	1.0788	2.6656	1.0866	2.5558	58
3	1.0645	2.9168	1.0715	2.7841	1.0789	2.6637	1.0868	2.5540	57
4	1.0646	2.9145	1.0716	2.7820	1.0790	2.6618	1.0869	2.5523	56
5	1.0647	2.9122	1.0717	2.7799	1.0792	2.6599	1.0870	2.5506	55
6	1.0648	2.9098	1.0719	2.7778	1.0793	2.6580	1.0872	2.5488	54
7	1.0650	2.9075	1.0720	2.7757	1.0794	2.6561	1.0873	2.5471	53
8	1.0651	2.9052	1.0721	2.7736	1.0795	2.6542	1.0874	2.5453	52
9	1.0652	2.9029	1.0722	2.7715	1.0797	2.6523	1.0876	2.5436	51
10	1.0653	2.9006	1.0723	2.7694	1.0798	2.6504	1.0877	2.5419	50
11	1.0654	2.8983	1.0725	2.7674	1.0799	2.6485	1.0878	2.5402	49
12	1.0655	2.8960	1.0726	2.7653	1.0801	2.6466	1.0880	2.5384	48
13	1.0656	2.8937	1.0727	2.7632	1.0802	2.6447	1.0881	2.5367	47
14	1.0658	2.8915	1.0728	2.7611	1.0803	2.6428	1.0882	2.5350	46
15	1.0659	2.8892	1.0729	2.7591	1.0804	2.6410	1.0884	2.5333	45
16	1.0660	2.8869	1.0731	2.7570	1.0806	2.6391	1.0885	2.5316	44
17	1.0661	2.8846	1.0732	2.7550	1.0807	2.6372	1.0886	2.5299	43
18	1.0662	2.8824	1.0733	2.7529	1.0808	2.6353	1.0888	2.5281	42
19	1.0663	2.8801	1.0734	2.7509	1.0810	2.6335	1.0889	2.5264	41
20	1.0664	2.8778	1.0736	2.7488	1.0811	2.6316	1.0891	2.5247	40
21	1.0666	2.8756	1.0737	2.7468	1.0812	2.6297	1.0892	2.5230	39
22	1.0667	2.8733	1.0738	2.7447	1.0813	2.6279	1.0893	2.5213	38
23	1.0668	2.8711	1.0739	2.7427	1.0815	2.6260	1.0895	2.5196	37
24	1.0669	2.8688	1.0740	2.7406	1.0816	2.6242	1.0896	2.5179	36
25	1.0670	2.8666	1.0742	2.7386	1.0817	2.6223	1.0897	2.5163	35
26	1.0671	2.8644	1.0743	2.7366	1.0819	2.6205	1.0899	2.5146	34
27	1.0673	2.8621	1.0744	2.7346	1.0820	2.6186	1.0900	2.5129	33
28	1.0674	2.8599	1.0745	2.7325	1.0821	2.6168	1.0902	2.5112	32
29	1.0675	2.8577	1.0747	2.7305	1.0823	2.6150	1.0903	2.5095	31
30	1.0676	2.8554	1.0748	2.7285	1.0824	2.6131	1.0904	2.5078	30
31	1.0677	2.8532	1.0749	2.7265	1.0825	2.6113	1.0906	2.5062	29
32	1.0678	2.8510	1.0750	2.7245	1.0826	2.6095	1.0907	2.5045	28
33	1.0679	2.8488	1.0751	2.7225	1.0828	2.6076	1.0908	2.5028	27
34	1.0681	2.8466	1.0753	2.7205	1.0829	2.6058	1.0910	2.5011	26
35	1.0682	2.8444	1.0754	2.7185	1.0830	2.6040	1.0911	2.4995	25
36	1.0683	2.8422	1.0755	2.7165	1.0832	2.6022	1.0913	2.4978	24
37	1.0684	2.8400	1.0756	2.7145	1.0833	2.6003	1.0914	2.4961	23
38	1.0685	2.8378	1.0758	2.7125	1.0834	2.5985	1.0915	2.4945	22
39	1.0686	2.8356	1.0759	2.7105	1.0836	2.5967	1.0917	2.4928	21
40	1.0688	2.8334	1.0760	2.7085	1.0837	2.5949	1.0918	2.4912	20
41	1.0689	2.8312	1.0761	2.7065	1.0838	2.5931	1.0920	2.4895	19
42	1.0690	2.8290	1.0763	2.7045	1.0840	2.5913	1.0921	2.4879	18
43	1.0691	2.8269	1.0764	2.7026	1.0841	2.5895	1.0922	2.4862	17
44	1.0692	2.8247	1.0765	2.7006	1.0842	2.5877	1.0924	2.4846	16
45	1.0694	2.8225	1.0766	2.6986	1.0844	2.5859	1.0925	2.4829	15
46	1.0695	2.8204	1.0768	2.6967	1.0845	2.5841	1.0927	2.4813	14
47	1.0696	2.8182	1.0769	2.6947	1.0846	2.5823	1.0928	2.4797	13
48	1.0697	2.8160	1.0770	2.6927	1.0847	2.5805	1.0929	2.4780	12
49	1.0698	2.8139	1.0771	2.6908	1.0849	2.5787	1.0931	2.4764	11
50	1.0699	2.8117	1.0773	2.6888	1.0850	2.5770	1.0932	2.4748	10
51	1.0701	2.8096	1.0774	2.6869	1.0851	2.5752	1.0934	2.4731	9
52	1.0702	2.8074	1.0775	2.6849	1.0853	2.5734	1.0935	2.4715	8
53	1.0703	2.8053	1.0776	2.6830	1.0854	2.5716	1.0936	2.4699	7
54	1.0704	2.8032	1.0778	2.6810	1.0855	2.5699	1.0938	2.4683	6
55	1.0705	2.8010	1.0779	2.6791	1.0857	2.5681	1.0939	2.4666	5
56	1.0707	2.7989	1.0780	2.6772	1.0858	2.5663	1.0941	2.4650	4
57	1.0708	2.7968	1.0781	2.6752	1.0859	2.5646	1.0942	2.4634	3
58	1.0709	2.7947	1.0783	2.6733	1.0861	2.5628	1.0943	2.4618	2
59	1.0710	2.7925	1.0784	2.6714	1.0862	2.5610	1.0945	2.4602	1
60	1.0711	2.7904	1.0785	2.6695	1.0864	2.5593	1.0946	2.4586	0
′	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	′
	69°		68°		67°		66°		

	24°		25°		26°		27°		
′	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	′
0	1.0946	2.4586	1.1034	2.3662	1.1126	2.2812	1.1223	2.2027	60
1	1.0948	2.4570	1.1035	2.3647	1.1127	2.2798	1.1225	2.2014	59
2	1.0949	2.4554	1.1037	2.3632	1.1129	2.2784	1.1226	2.2002	58
3	1.0951	2.4538	1.1038	2.3618	1.1131	2.2771	1.1228	2.1989	57
4	1.0952	2.4522	1.1040	2.3603	1.1132	2.2757	1.1230	2.1977	56
5	1.0953	2.4506	1.1041	2.3588	1.1134	2.2744	1.1231	2.1964	55
6	1.0955	2.4490	1.1043	2.3574	1.1135	2.2730	1.1233	2.1952	54
7	1.0956	2.4474	1.1044	2.3559	1.1137	2.2717	1.1235	2.1939	53
8	1.0958	2.4458	1.1046	2.3544	1.1139	2.2703	1.1237	2.1927	52
9	1.0959	2.4442	1.1047	2.3530	1.1140	2.2690	1.1238	2.1914	51
10	1.0961	2.4426	1.1049	2.3515	1.1142	2.2676	1.1240	2.1902	50
11	1.0962	2.4411	1.1050	2.3501	1.1143	2.2663	1.1242	2.1889	49
12	1.0963	2.4395	1.1052	2.3486	1.1145	2.2650	1.1243	2.1877	48
13	1.0965	2.4379	1.1053	2.3472	1.1147	2.2636	1.1245	2.1865	47
14	1.0966	2.4363	1.1055	2.3457	1.1148	2 2623	1.1247	2.1852	46
15	1.0968	2.4347	1.1056	2.3443	1.1150	2.2610	1.1248	2.1840	45
16	1.0969	2.4332	1.1058	2.3428	1.1151	2.2596	1.1250	2.1828	44
17	1.0971	2.4316	1.1059	2.3414	1.1153	2.2583	1.1252	2.1815	43
18	1.0972	2.4300	1.1061	2.3399	1.1155	2.2570	1.1253	2.1803	42
19	1.0973	2.4285	1.1062	2.3385	1.1156	2.2556	1.1255	2.1791	41
20	1.0975	2.4269	1.1064	2.3371	1.1158	2.2543	1.1257	2.1778	40
21	1.0976	2.4254	1.1065	2.3356	1.1159	2.2530	1.1258	2.1766	39
22	1.0978	2.4238	1.1067	2.3342	1.1161	2.2517	1.1260	2.1754	38
23	1.0979	2.4222	1.1068	2.3328	1.1163	2.2503	1.1262	2.1742	37
24	1.0981	2.4207	1.1070	2.3313	1.1164	2.2490	1.1264	2.1730	36
25	1.0982	2.4191	1.1072	2.3299	1.1166	2.2477	1.1265	2.1717	35
26	1.0984	2.4176	1.1073	2.3285	1.1167	2.2464	1.1267	2.1705	34
27	1.0985	2.4160	1.1075	2.3271	1.1169	2.2451	1.1269	2.1693	33
28	1.0986	2.4145	1.1076	2.3256	1.1171	2.2438	1.1270	2.1681	32
29	1.0988	2.4130	1.1078	2.3242	1.1172	2.2425	1.1272	2.1669	31
30	1.0989	2.4114	1.1079	2.3228	1.1174	2.2411	1.1274	2.1657	30
31	1.0991	2.4099	1.1081	2.3214	1.1176	2.2398	1.1275	2.1645	29
32	1.0992	2.4083	1.1082	2.3200	1.1177	2.2385	1.1277	2.1633	28
33	1.0994	2.4068	1.1084	2.3186	1.1179	2.2372	1.1279	2.1620	27
34	1.0995	2.4053	1.1085	2.3172	1.1180	2.2359	1.1281	2.1608	26
35	1.0997	2.4037	1.1087	2.3158	1.1182	2.2346	1.1282	2.1596	25
36	1.0998	2.4022	1.1088	2.3143	1.1184	2.2333	1.1284	2.1584	24
37	1.1000	2.4007	1.1090	2.3129	1.1185	2.2320	1.1286	2.1572	23
38	1.1001	2.3992	1.1092	2.3115	1.1187	2.2307	1.1287	2.1560	22
39	1.1003	2.3976	1.1093	2.3101	1.1189	2.2294	1.1289	2.1548	21
40	1.1004	2.3961	1.1095	2.3087	1.1190	2.2282	1.1291	2.1536	20
41	1.1005	2.3946	1.1096	2.3073	1.1192	2.2269	1.1293	2.1525	19
42	1.1007	2.3931	1.1098	2.3059	1.1193	2.2256	1.1294	2.1513	18
43	1.1008	2.3916	1.1099	2.3046	1.1195	2.2243	1.1296	2.1501	17
44	1.1010	2.3901	1.1101	2.3032	1.1197	2.2230	1.1298	2.1489	16
45	1.1011	2.3886	1.1102	2.3018	1.1198	2.2217	1.1299	2.1477	15
46	1.1013	2.3871	1.1104	2.3004	1.1200	2.2204	1.1301	2.1465	14
47	1.1014	2.3856	1.1106	2.2990	1.1202	2.2192	1.1303	2.1453	13
48	1.1016	2.3841	1.1107	2.2976	1.1203	2.2179	1.1305	2.1441	12
49	1.1017	2.3826	1.1109	2.2962	1.1205	2.2166	1.1306	2.1430	11
50	1.1019	2.3811	1.1110	2.2949	1.1207	2.2153	1.1308	2.1418	10
51	1.1020	2.3796	1.1112	2.2935	1.1208	2.2141	1.1310	2.1406	9
52	1.1022	2.3781	1.1113	2.2921	1.1210	2.2128	1.1312	2.1394	8
53	1.1023	2.3766	1.1115	2.2907	1.1212	2.2115	1.1313	2.1382	7
54	1.1025	2.3751	1.1116	2.2894	1.1213	2.2103	1.1315	2.1371	6
55	1.1026	2.3736	1.1118	2.2880	1.1215	2.2090	1.1317	2.1359	5
56	1.1028	2.3721	1.1120	2.2866	1.1217	2.2077	1.1319	2.1347	4
57	1.1029	2.3706	1.1121	2.2853	1.1218	2.2065	1.1320	2.1335	3
58	1.1031	2.3691	1.1123	2.2830	1.1220	2.2052	1.1322	2.1324	2
59	1.1032	2.3677	1.1124	2.2825	1.1222	2.2039	1.1324	2.1312	1
60	1.1034	2.3662	1.1126	2.2812	1.1223	2.2027	1.1326	2.1300	0
′	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	′
	65°		64°		63°		62°		

	28°		29°		30°		31°		
′	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	′
0	1.1326	2.1300	1.1433	2.0627	1.1547	2.0000	1.1666	1.9416	60
1	1.1327	2.1289	1.1435	2.0616	1.1549	1.9990	1.1668	1.9407	59
2	1.1329	2.1277	1.1437	2.0605	1.1551	1.9980	1.1670	1.9397	58
3	1.1331	2.1266	1.1439	2.0594	1.1553	1.9970	1.1672	1.9388	57
4	1.1333	2.1254	1.1441	2.0583	1.1555	1.9960	1.1674	1.9378	56
5	1.1334	2.1242	1.1443	2.0573	1.1557	1.9950	1.1676	1.9369	55
6	1.1336	2.1231	1.1445	2.0562	1.1559	1.9940	1.1678	1.9360	54
7	1.1338	2.1219	1.1446	2.0551	1.1561	1.9930	1.1681	1.9350	53
8	1.1340	2.1208	1.1448	2.0540	1.1562	1.9920	1.1683	1.9341	52
9	1.1341	2.1196	1.1450	2.0530	1.1564	1.9910	1.1685	1.9332	51
10	1.1343	2.1185	1.1452	2.0519	1.1566	1.9900	1.1687	1.9322	50
11	1.1345	2.1173	1.1454	2.0508	1.1568	1.9890	1.1689	1.9313	49
12	1.1347	2.1162	1.1456	2.0498	1.1570	1.9880	1.1691	1.9304	48
13	1.1349	2.1150	1.1458	2.0487	1.1572	1.9870	1.1693	1.9295	47
14	1.1350	2.1139	1.1459	2.0476	1.1574	1.9860	1.1695	1.9285	46
15	1.1352	2.1127	1.1461	2.0466	1.1576	1.9850	1.1697	1.9276	45
16	1.1354	2.1116	1.1463	2.0455	1.1578	1.9840	1.1699	1.9267	44
17	1.1356	2.1104	1.1465	2.0444	1.1580	1.9830	1.1701	1.9258	43
18	1.1357	2.1093	1.1467	2.0434	1.1582	1.9820	1.1703	1.9248	42
19	1.1359	2.1082	1.1469	2.0423	1.1584	1.9811	1.1705	1.9239	41
20	1.1361	2.1070	1.1471	2.0413	1.1586	1.9801	1.1707	1.9230	40
21	1.1363	2.1059	1.1473	2.0402	1.1588	1.9791	1.1709	1.9221	39
22	1.1365	2.1048	1.1474	2.0392	1.1590	1.9781	1.1712	1.9212	38
23	1.1366	2.1036	1.1476	2.0381	1.1592	1.9771	1.1714	1.9203	37
24	1.1368	2.1025	1.1478	2.0370	1.1594	1.9761	1.1716	1.9193	36
25	1.1370	2.1014	1.1480	2.0360	1.1596	1.9752	1.1718	1.9184	35
26	1.1372	2.1002	1.1482	2.0349	1.1598	1.9742	1.1720	1.9175	34
27	1.1373	2.0991	1.1484	2.0339	1.1600	1.9732	1.1722	1.9166	33
28	1.1375	2.0980	1.1486	2.0329	1.1602	1.9722	1.1724	1.9157	32
29	1.1377	2.0969	1.1488	2.0318	1.1604	1.9713	1.1726	1.9148	31
30	1.1379	2.0957	1.1489	2.0308	1.1606	1.9703	1.1728	1.9139	30
31	1.1381	2.0946	1.1491	2.0297	1.1608	1.9693	1.1730	1.9130	29
32	1.1382	2.0935	1.1493	2.0287	1.1610	1.9683	1.1732	1.9121	28
33	1.1384	2.0924	1.1495	2.0276	1.1612	1.9674	1.1734	1.9112	27
34	1.1386	2.0912	1.1497	2.0266	1.1614	1.9664	1.1737	1.9102	26
35	1.1388	2.0901	1.1499	2.0256	1.1616	1.9654	1.1739	1.9093	25
36	1.1390	2.0890	1.1501	2.0245	1.1618	1.9645	1.1741	1.9084	24
37	1.1391	2.0879	1.1503	2.0235	1.1620	1.9635	1.1743	1.9075	23
38	1.1393	2.0868	1.1505	2.0224	1.1622	1.9625	1.1745	1.9066	22
39	1.1395	2.0857	1.1507	2.0214	1.1624	1.9616	1.1747	1.9057	21
40	1.1397	2.0846	1.1508	2.0204	1.1626	1.9606	1.1749	1.9048	20
41	1.1399	2.0835	1.1510	2.0194	1.1628	1.9596	1.1751	1.9039	19
42	1.1401	2.0824	1.1512	2.0183	1.1630	1.9587	1.1753	1.9030	18
43	1.1402	2.0812	1.1514	2.0173	1.1632	1.9577	1.1756	1.9021	17
44	1.1404	2.0801	1.1516	2.0163	1.1634	1.9568	1.1758	1.9013	16
45	1.1406	2.0790	1.1518	2.0152	1.1636	1.9558	1.1760	1.9004	15
46	1.1408	2.0779	1.1520	2.0142	1.1638	1.9549	1.1762	1.8995	14
47	1.1410	2.0768	1.1522	2.0132	1.1640	1.9539	1.1764	1.8986	13
48	1.1411	2.0757	1.1524	2.0122	1.1642	1.9530	1.1766	1.8977	12
49	1.1413	2.0746	1.1526	2.0111	1.1644	1.9520	1.1768	1.8968	11
50	1.1415	2.0735	1.1528	2.0101	1.1646	1.9510	1.1770	1.8959	10
51	1.1417	2.0725	1.1530	2.0091	1.1648	1.9501	1.1772	1.8950	9
52	1.1419	2.0714	1.1531	2.0081	1.1650	1.9491	1.1775	1.8941	8
53	1.1421	2.0703	1.1533	2.0071	1.1652	1.9482	1.1777	1.8932	7
54	1.1422	2.0692	1.1535	2.0061	1.1654	1.9473	1.1779	1.8924	6
55	1.1424	2.0681	1.1537	2.0050	1.1656	1.9463	1.1781	1.8915	5
56	1.1426	2.0670	1.1539	2.0040	1.1658	1.9454	1.1783	1.8906	4
57	1.1428	2.0659	1.1541	2.0030	1.1660	1.9444	1.1785	1.8897	3
58	1.1430	2.0648	1.1543	2.0020	1.1662	1.9435	1.1787	1.8888	2
59	1.1432	2.0637	1.1545	2.0010	1.1664	1.9425	1.1790	1.8879	1
60	1.1433	2.0627	1.1547	2.0000	1.1666	1.9416	1.1792	1.8871	0
′	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	′
	61°		60°		59°		58°		

	32°		33°		34°		35°		
′	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	′
0	1.1792	1.8871	1.1924	1.8361	1.2062	1.7883	1.2208	1.7434	60
1	1.1794	1.8862	1.1926	1.8352	1.2064	1.7875	1.2210	1.7427	59
2	1.1796	1.8853	1.1928	1.8344	1.2067	1.7867	1.2213	1.7420	58
3	1.1798	1.8844	1.1930	1.8336	1.2069	1.7860	1.2215	1.7413	57
4	1.1800	1.8836	1.1933	1.8328	1.2072	1.7852	1.2218	1.7405	56
5	1.1802	1.8827	1.1935	1.8320	1.2074	1.7844	1.2220	1.7398	55
6	1.1805	1.8818	1.1937	1.8311	1.2076	1.7837	1.2223	1.7391	54
7	1.1807	1.8809	1.1939	1.8303	1.2079	1.7829	1.2225	1.7384	53
8	1.1809	1.8801	1.1942	1.8295	1.2081	1.7821	1.2228	1.7377	52
9	1.1811	1.8792	1.1944	1.8287	1.2083	1.7814	1.2230	1.7369	51
10	1.1813	1.8783	1.1946	1.8279	1.2086	1.7806	1.2233	1.7362	50
11	1.1815	1.8785	1.1948	1.8271	1.2088	1.7798	1.2235	1.7355	49
12	1.1818	1.8766	1.1951	1.8263	1.2091	1.7791	1.2238	1.7348	48
13	1.1820	1.8757	1.1953	1.8255	1.2093	1.7783	1.2240	1.7341	47
14	1.1822	1.8749	1.1955	1.8246	1.2095	1.7776	1.2243	1.7334	46
15	1.1824	1.8740	1.1958	1.8238	1.2098	1.7768	1.2245	1.7327	45
16	1.1826	1.8731	1.1960	1.8230	1.2100	1.7760	1.2248	1.7319	44
17	1.1828	1.8723	1.1962	1.8222	1.2103	1.7753	1.2250	1.7312	43
18	1.1831	1.8714	1.1964	1.8214	1.2105	1.7745	1.2253	1.7305	42
19	1.1833	1.8706	1.1967	1.8206	1.2107	1.7738	1.2255	1.7298	41
20	1.1835	1.8697	1.1969	1.8198	1.2110	1.7730	1.2258	1.7291	40
21	1.1837	1.8688	1.1971	1.8190	1.2112	1.7723	1.2260	1.7284	39
22	1.1839	1.8680	1.1974	1.8182	1.2115	1.7715	1.2263	1.7277	38
23	1.1841	1.8671	1.1976	1.8174	1.2117	1.7708	1.2265	1.7270	37
24	1.1844	1.8663	1.1978	1.8166	1.2119	1.7700	1.2268	1.7263	36
25	1.1846	1.8654	1.1980	1.8158	1.2122	1.7693	1.2270	1.7256	35
26	1.1848	1.8646	1.1983	1.8150	1.2124	1.7685	1.2273	1.7249	34
27	1.1850	1.8637	1.1985	1.8142	1.2127	1.7678	1.2276	1.7242	33
28	1.1852	1.8629	1.1987	1.8134	1.2129	1.7670	1.2278	1.7234	32
29	1.1855	1.8620	1.1990	1.8126	1.2132	1.7663	1.2281	1.7227	31
30	1.1857	1.8611	1.1992	1.8118	1.2134	1.7655	1.2283	1.7220	30
31	1.1859	1.8603	1.1994	1.8110	1.2136	1.7648	1.2286	1.7213	29
32	1.1861	1.8595	1.1997	1.8102	1.2139	1.7640	1.2288	1.7206	28
33	1.1863	1.8586	1.1999	1.8094	1.2141	1.7633	1.2291	1.7199	27
34	1.1866	1.8578	1.2001	1.8086	1.2144	1.7625	1.2293	1.7192	26
35	1.1868	1.8569	1.2004	1.8078	1.2146	1.7618	1.2296	1.7185	25
36	1.1870	1.8561	1.2006	1.8070	1.2149	1.7610	1.2298	1.7178	24
37	1.1872	1.8552	1.2008	1.8062	1.2151	1.7603	1.2301	1.7171	23
38	1.1874	1.8544	1.2010	1.8054	1.2153	1.7596	1.2304	1.7164	22
39	1.1877	1.8535	1.2013	1.8047	1.2156	1.7588	1.2306	1.7157	21
40	1.1879	1.8527	1.2015	1.8039	1.2158	1.7581	1.2309	1.7151	20
41	1.1881	1.8519	1.2017	1.8031	1.2161	1.7573	1.2311	1.7144	19
42	1.1883	1.8510	1.2020	1.8023	1.2163	1.7566	1.2314	1.7137	18
43	1.1886	1.8502	1.2022	1.8015	1.2166	1.7559	1.2316	1.7130	17
44	1.1888	1.8493	1.2024	1.8007	1.2168	1.7551	1.2319	1.7123	16
45	1.1890	1.8485	1.2027	1.7999	1.2171	1.7544	1.2322	1.7116	15
46	1.1892	1.8477	1.2029	1.7992	1.2173	1.7537	1.2324	1.7109	14
47	1.1894	1.8468	1.2031	1.7984	1.2175	1.7529	1.2327	1.7102	13
48	1.1897	1.8460	1.2034	1.7976	1.2178	1.7522	1.2329	1.7095	12
49	1.1899	1.8452	1.2036	1.7968	1.2180	1.7514	1.2332	1.7088	11
50	1.1901	1.8443	1.2039	1.7960	1.2183	1.7507	1.2335	1.7081	10
51	1.1903	1.8435	1.2041	1.7953	1.2185	1.7500	1.2337	1.7075	9
52	1.1906	1.8427	1.2043	1.7945	1.2188	1.7493	1.2340	1.7068	8
53	1.1908	1.8418	1.2046	1.7937	1.2190	1.7485	1.2342	1.7061	7
54	1.1910	1.8410	1.2048	1.7929	1.2193	1.7478	1.2345	1.7054	6
55	1.1912	1.8402	1.2050	1.7921	1.2195	1.7471	1.2348	1.7047	5
56	1.1915	1.8394	1.2053	1.7914	1.2198	1.7463	1.2350	1.7040	4
57	1.1917	1.8385	1.2055	1.7906	1.2200	1.7456	1.2353	1.7033	3
58	1.1919	1.8377	1.2057	1.7898	1.2203	1.7449	1.2355	1.7027	2
59	1.1921	1.8369	1.2060	1.7891	1.2205	1.7442	1.2358	1.7020	1
60	1.1922	1.8361	1.2062	1.7883	1.2208	1.7434	1.2361	1.7013	0
′	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	′
	57°		56°		55°		54°		

	36°		37°		38°		39°		
′	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	′
0	1.2361	1.7013	1.2521	1.6616	1.2690	1.6243	1.2867	1.5890	60
1	1.2363	1.7006	1.2524	1.6610	1 2693	1.6237	1.2871	1.5884	59
2	1.2366	1.6999	1.2527	1.6603	1.2696	1.6231	1.2874	1.5879	58
3	1.2368	1.6993	1.2530	1.6597	1.2699	1.6224	1.2877	1.5873	57
4	1.2371	1.6986	1.2532	1.6591	1.2702	1.6218	1.2880	1.5867	56
5	1.2374	1.6979	1.2535	1.6584	1.2705	1.6212	1.2883	1.5862	55
6	1.2376	1.6972	1.2538	1.6578	1.2707	1.6206	1.2886	1.5856	54
7	1.2379	1.6965	1.2541	1.6572	1.2710	1.6200	1.2889	1.5850	53
8	1.2382	1.6959	1.2543	1.6565	1.2713	1.6194	1.2892	1.5845	52
9	1.2384	1.6952	1.2546	1.6559	1.2716	1.6188	1.2895	1.5839	51
10	1.2387	1.6945	1.2549	1.6552	1.2719	1.6182	1.2898	1.5833	50
11	1.2389	1.6938	1.2552	1.6546	1.2722	1.6176	1.2901	1.5828	49
12	1.2392	1.6932	1.2554	1.6540	1.2725	1.6170	1.2904	1.5822	48
13	1.2395	1.6925	1.2557	1.6533	1.2728	1.6164	1.2907	1.5816	47
14	1.2397	1.6918	1.2560	1.6527	1.2731	1.6159	1.2910	1.5811	46
15	1.2400	1.6912	1.2563	1.6521	1.2734	1.6153	1.2913	1.5805	45
16	1.2403	1.6905	1.2565	1.6514	1.2737	1.6147	1.2916	1.5799	44
17	1.2405	1.6898	1.2568	1.6508	1.2739	1.6141	1.2919	1.5794	43
18	1.2408	1.6891	1.2571	1.6502	1.2742	1.6135	1.2922	1.5788	42
19	1.2411	1.6885	1.2574	1.6496	1.2745	1.6129	1.2926	1.5783	41
20	1.2413	1.6878	1.2577	1.6489	1.2748	1.6123	1.2929	1.5777	40
21	1.2416	1.6871	1.2579	1.6483	1.2751	1.6117	1.2932	1.5771	39
22	1.2419	1.6865	1.2582	1.6477	1.2754	1.6111	1.2935	1.5766	38
23	1.2421	1.6858	1.2585	1.6470	1.2757	1.6105	1.2938	1.5760	37
24	1.2424	1.6851	1.2588	1.6464	1.2760	1.6099	1.2941	1.5755	36
25	1.2427	1.6845	1.2591	1.6458	1.2763	1.6093	1.2944	1.5749	35
26	1.2429	1.6838	1.2593	1.6452	1.2766	1.6087	1.2947	1.5743	34
27	1.2432	1.6831	1.2596	1.6445	1.2769	1.6081	1.2950	1.5738	33
28	1.2435	1.6825	1.2599	1.6439	1.2772	1.6077	1.2953	1.5732	32
29	1.2437	1.6818	1.2602	1.6433	1.2775	1.6070	1.2956	1.5727	31
30	1.2440	1.6812	1.2605	1.6427	1.2778	1.6064	1.2960	1.5721	30
31	1.2443	1.6805	1.2607	1.6420	1.2781	1.6058	1.2963	1.5716	29
32	1.2445	1.6798	1.2610	1.6414	1.2784	1.6052	1.2966	1.5710	28
33	1.2448	1.6792	1.2613	1.6408	1.2787	1.6046	1.2969	1.5705	27
34	1.2451	1.6785	1.2616	1.6402	1.2790	1.6040	1.2972	1.5699	26
35	1.2453	1.6779	1.2619	1.6396	1.2793	1.6034	1.2975	1.5694	25
36	1.2456	1.6772	1.2622	1.6389	1.2795	1.6029	1.2978	1.5688	24
37	1.2459	1.6766	1.2624	1.6383	1.2798	1.6023	1.2981	1.5683	23
38	1.2461	1.6759	1.2627	1.6377	1.2801	1.6017	1.2985	1.5677	22
39	1.2464	1.6752	1.2630	1.6371	1.2804	1.6011	1.2988	1.5672	21
40	1.2467	1.6746	1.2633	1.6365	1.2807	1.6005	1.2991	1.5666	20
41	1.2470	1.6739	1.2636	1.6359	1.2810	1.6000	1.2994	1.5661	19
42	1.2472	1.6733	1.2639	1.6352	1.2813	1.5994	1.2997	1.5655	18
43	1.2475	1.6726	1.2641	1.6346	1.2816	1.5988	1.3000	1.5650	17
44	1.2478	1.6720	1.2644	1.6340	1.2819	1.5982	1.3003	1.5644	16
45	1.2480	1.6713	1.2647	1.6334	1.2822	1.5976	1.3006	1.5639	15
46	1.2483	1.6707	1.2650	1.6328	1.2825	1.5971	1.3010	1.5633	14
47	1.2486	1.6700	1.2653	1.6322	1.2828	1.5965	1.3013	1.5628	13
48	1.2488	1.6694	1.2656	1.6316	1.2831	1.5959	1.3016	1.5622	12
49	1.2490	1.6687	1.2659	1.6309	1.2834	1.5953	1.3019	1.5617	11
50	1.2494	1.6681	1.2661	1.6303	1.2837	1.5947	1.3022	1.5611	10
51	1.2497	1.6674	1.2664	1.6297	1.2840	1.5942	1.3025	1.5606	9
52	1.2499	1.6668	1.2667	1.6291	1.2843	1.5936	1.3029	1.5600	8
53	1.2502	1.6661	1.2670	1.6285	1.2846	1.5930	1.3032	1.5595	7
54	1.2505	1.6655	1.2673	1.6279	1.2849	1.5924	1.3035	1.5590	6
55	1.2508	1.6648	1.2676	1.6273	1.2852	1.5919	1.3038	1.5584	5
56	1.2510	1.6642	1.2679	1.6267	1.2855	1.5913	1.3041	1.5579	4
57	1.2513	1.6636	1.2681	1.6261	1.2858	1.5907	1.3044	1.5573	3
58	1.2516	1.6629	1.2684	1.6255	1.2861	1.5901	1.3048	1.5568	2
59	1.2519	1.6623	1.2687	1.6249	1.2864	1.5896	1.3051	1.5563	1
60	1.2521	1.6616	1.2690	1.6243	1.2867	1.5890	1.3054	1.5557	0
′	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	′
	53°		52°		51°		50°		

	40°		41°		42°		43°		
′	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	′
0	1.3054	1.5557	1.3250	1.5242	1.3456	1.4945	1.3673	1.4663	60
1	1.3057	1.5552	1.3253	1.5237	1.3460	1.4940	1.3677	1.4658	59
2	1.3060	1.5546	1.3257	1.5232	1.3463	1.4935	1.3681	1.4654	58
3	1.3064	1.5541	1.3260	1.5227	1.3467	1.4930	1.3684	1.4649	57
4	1.3067	1.5536	1.3263	1.5222	1.3470	1.4925	1.3688	1.4644	56
5	1.3070	1.5530	1.3267	1.5217	1.3474	1.4921	1.3692	1.4640	55
6	1.3073	1.5525	1.3270	1.5212	1.3477	1.4916	1.3695	1.4635	54
7	1.3076	1.5520	1.3274	1.5207	1.3481	1.4911	1.3699	1.4631	53
8	1.3080	1.5514	1.3277	1.5202	1.3485	1.4906	1.3703	1.4626	52
9	1.3083	1.5509	1.3280	1.5197	1.3488	1.4901	1.3707	1.4622	51
10	1.3086	1.5503	1.3284	1.5192	1.3492	1.4897	1.3710	1.4617	50
11	1.3089	1.5498	1.3287	1.5187	1.3495	1.4892	1.3714	1.4613	49
12	1.3092	1 5493	1.3290	1.5182	1.3499	1.4887	1.3718	1.4608	48
13	1.3096	1.5487	1.3294	1.5177	1 3502	1.4882	1.3722	1.4604	47
14	1.3099	1.5482	1.3297	1.5171	1.3506	1.4877	1.3725	1.4599	46
15	1.3102	1.5477	1.3301	1.5166	1.3509	1.4873	1.3729	1.4595	45
16	1.3105	1.5471	1.3304	1.5161	1.3513	1.4868	1.3733	1.4590	44
17	1.3109	1.5466	1.3307	1.5156	1.3517	1.4863	1.3737	1.4586	43
18	1.3112	1.5461	1.3311	1.5151	1.3520	1.4858	1.3740	1.4581	42
19	1.3115	1.5456	1.3314	1.5146	1.3524	1.4854	1.3744	1.4577	41
20	1.3118	1.5450	1.3318	1.5141	1.3527	1.4849	1.3748	1.4572	40
21	1.3121	1.5445	1.3321	1.5136	1.3531	1.4844	1.3752	1.4568	39
22	1.3125	1.5440	1.3324	1.5131	1.3534	1.4839	1.3756	1.4563	38
23	1.3128	1.5434	1.3328	1.5126	1.3538	1.4835	1.3759	1.4559	37
24	1.3131	1.5429	1.3331	1.5121	1.3542	1.4830	1.3763	1.4554	36
25	1.3134	1.5424	1.3335	1.5116	1.3545	1.4825	1.3767	1.4550	35
26	1.3138	1.5419	1.3338	1.5111	1.3549	1.4821	1.3771	1.4545	34
27	1.3141	1.5413	1.3342	1.5106	1.3552	1.4816	1.3774	1.4541	33
28	1.3144	1.5408	1.3345	1.5101	1.3556	1.4811	1.3778	1.4536	32
29	1.3148	1.5403	1.3348	1.5096	1.3560	1.4806	1.3782	1.4532	31
30	1.3151	1.5398	1.3352	1.5092	1.3563	1.4802	1.3786	1.4527	30
31	1.3154	1.5392	1.3355	1.5087	1.3567	1.4797	1.3790	1.4523	29
32	1.3157	1.5387	1.3359	1.5082	1.3571	1.4792	1.3794	1.4518	28
33	1.3161	1.5382	1.3362	1.5077	1.3574	1.4788	1.3797	1 4514	27
34	1.3164	1.5377	1.3366	1.5072	1.3578	1.4783	1.3801	1.4510	26
35	1.3167	1.5371	1.3369	1.5067	1.3581	1.4778	1.3805	1.4505	25
36	1.3170	1.5366	1.3372	1.5062	1.3585	1.4774	1.3809	1.4501	24
37	1.3174	1.5361	1.3376	1.5057	1.3589	1.4769	1.3813	1.4496	23
38	1.3177	1.5356	1.3379	1.5052	1.3592	1.4764	1.3816	1.4492	22
39	1.3180	1.5351	1.3383	1.5047	1.3596	1.4760	1.3820	1.4487	21
40	1.3184	1.5345	1.3386	1.5042	1.3600	1.4755	1.3824	1.4483	20
41	1.3187	1.5340	1.3390	1.5037	1.3603	1.4750	1.3828	1.4479	19
42	1.3190	1.5335	1.3393	1.5032	1.3607	1.4746	1.3832	1.4474	18
43	1.3193	1.5330	1.3397	1.5027	1.3611	1.4741	1.3836	1.4470	17
44	1.3197	1.5325	1.3400	1.5022	1.3614	1.4736	1.3839	1.4465	16
45	1.3200	1.5319	1.3404	1.5018	1.3618	1.4732	1.3843	1.4461	15
46	1.3203	1.5314	1.3407	1.5013	1.3622	1.4727	1.3847	1.4457	14
47	1.3207	1.5309	1.3411	1.5008	1.3625	1.4723	1.3851	1.4452	13
48	1.3210	1.5304	1.3414	1.5003	1.3629	1.4718	1.3855	1.4448	12
49	1.3213	1.5299	1.3418	1.4998	1.3633	1.4713	1.3859	1.4443	11
50	1.3217	1.5294	1.3421	1.4993	1.3636	1.4709	1.3863	1.4439	10
51	1.3220	1.5289	1.3425	1.4988	1.3640	1.4704	1.3867	1.4435	9
52	1.3223	1.5283	1.3428	1.4983	1.3644	1.4699	1.3870	1.4430	8
53	1.3227	1.5278	1.3432	1.4979	1.3647	1.4695	1.3874	1.4426	7
54	1.3230	1.5273	1.3435	1.4974	1.3651	1.4690	1.3878	1.4422	6
55	1.3233	1.5268	1.3439	1.4969	1.3655	1.4686	1.3882	1.4417	5
56	1.3237	1.5263	1.3442	1.4964	1.3658	1.4681	1.3886	1.4413	4
57	1.3240	1.5258	1.3446	1.4959	1.3662	1.4676	1.3890	1.4408	3
58	1.3243	1.5253	1.3449	1.4954	1.3666	1.4672	1.3894	1.4404	2
59	1.3247	1.5248	1.3453	1.4949	1.3669	1.4667	1.3898	1.4400	1
60	1.3250	1.5242	1.3456	1.4945	1.3673	1.4663	1.3902	1.4395	0
′	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	′
	49°		48°		47°		46°		

	44°				44°				44°		
′	Sec.	Co-sec.	′	′	Sec.	Co-sec.	′	′	Sec	Co-sec.	′
0	1.3902	1.4395	60	21	1.3984	1.4305	39	41	1.4065	1.4221	19
1	1.3905	1.4391	59	22	1.3988	1.4301	38	42	1.4069	1.4217	18
2	1.3909	1.4387	58	23	1.3992	1.4297	37	43	1.4073	1.4212	17
3	1.3913	1.4382	57	24	1.3996	1.4292	36	44	1.4077	1.4208	16
4	1.3917	1.4378	56	25	1.4000	1.4288	35	45	1.4081	1.4204	15
5	1.3921	1.4374	55	26	1.4004	1.4284	34	46	1.4085	1.4200	14
6	1.3925	1.4370	54	27	1.4008	1.4280	33	47	1.4089	1.4196	13
7	1.3929	1.4365	53	28	1.4012	1.4276	32	48	1.4093	1.4192	12
8	1.3933	1.4361	52	29	1.4016	1.4271	31	49	1.4097	1.4188	11
9	1.3937	1.4357	51	30	1.4020	1.4267	30	50	1.4101	1.4183	10
10	1.3941	1.4352	50	31	1.4024	1.4263	29	51	1.4105	1.4179	9
11	1.3945	1.4348	49	32	1.4028	1.4259	28	52	1.4109	1.4175	8
12	1.3949	1.4344	48	33	1.4032	1.4254	27	53	1.4113	1.4171	7
13	1.3953	1.4339	47	34	1.4036	1.4250	26	54	1.4117	1.4167	6
14	1.3957	1.4335	46	35	1.4040	1.4246	25	55	1.4122	1.4163	5
15	1.3960	1.4331	45	36	1.4044	1.4242	24	56	1.4126	1.4159	4
16	1.3964	1.4327	44	37	1.4048	1.4238	23	57	1.4130	1.4154	3
17	1.3968	1.4322	43	38	1.4052	1.4233	22	58	1.4134	1.4150	2
18	1.3972	1.4318	42	39	1.4056	1.4229	21	59	1.4138	1.4146	1
19	1.3976	1.4314	41	40	1.4060	1.4225	20	60	1.4142	1.4142	0
20	1.3980	1.4310	40								
′	Co-sec.	Sec.	′	′	Co-sec.	Sec.	′	′	Co-sec.	Sec.	′
	45°				45°				45°		

SINES OF SECONDS

It is convenient at times to use a table of sines of seconds to avoid having to interpolate for values between even minutes in a table of sines. Thus if we have an angle of 10 degrees, 30 minutes, 22 seconds, we can take the value for 10 degrees 30 minutes (0.18224) directly from the regular table of sines, then under this table of sines of seconds find the sine of 22 seconds (0.000106) which, added to 0.18234, gives us 0.18225 as the sine of the above angle.

SINES OF SECONDS

Seconds	Sine	Seconds	Sine	Seconds	Sine
1	0.0000048	21	0.0001018	41	0.0001987
2	0.0000096	22	0.0001066	42	0.0002036
3	0.0000145	23	0.0001115	43	0.0002084
4	0.0000193	24	0.0001163	44	0.0002133
5	0.0000242	25	0.0001212	45	0.0002181
6	0.0000290	26	0.0001260	46	0.0002230
7	0.0000339	27	0.0001309	47	0.0002278
8	0.0000387	28	0.0001367	48	0.0002327
9	0.0000436	29	0.0001406	49	0.0002375
10	0.0000484	30	0.0001454	50	0.0002424
11	0.0000532	31	0.0001502	51	0.0002472
12	0.0000581	32	0.0001551	52	0.0002521
13	0.0000630	33	0.0001599	53	0.0002569
14	0.0000678	34	0.0001648	54	0.0002618
15	0.0000727	35	0.0001699	55	0.0002666
16	0.0000775	36	0.0001745	56	0.0002715
17	0.0000824	37	0.0001793	57	0.0002763
18	0.0000872	38	0.0001842	58	0.0002811
19	0.0000921	39	0.0001890	59	0.0002860
20	0.0000969	40	0.0001939	60	0.0002908

NOTE.—For angles above 20 degrees the following values can be taken for the *sine of* 1 *second* if increased accuracy is required: 20 to 30 degrees, 0.0000045; 30 to 40 degrees, 0.0000038; 40 to 50 degrees, 0.0000033; 50 to 60 degrees, 0.0000026. Multiply the given constant by the number of seconds in the problem.

SECTION XXVIII

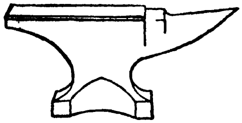
DICTIONARY OF SHOP TERMS

A

Aero-thread—A system for use in soft metals in which a helical steel coil is used between the tapped hole and the stud.

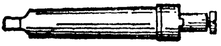
Allowance—Desired difference in dimensions of mating parts. A working clearance not to be confused with tolerance.

Angle Irons or Plates—Usually castings, for holding work at any desired angle to the cutting tool. Made for use on the face-plate of a lathe or table of milling machine, planer, boring mill, etc.



Anvils—Blocks of iron or steel on which metals are hammered or forged. Usually have a steel face. A square hole is usually provided for holding hardies, fuller blocks, etc.

Apron—A protecting or covering plate that encloses any mechanism, such as the apron of a lathe.



Arbor—A shaft or bar for holding *cutting tools*. Frequently has a taper shank fitting the spindle of a machine. The term was formerly used interchangeably with "mandrel" on which *work* is held. See Mandrel.

B

Babbitt Metal—A general name applied to soft bearing metals. Named after man who devised a good tin and copper alloy. Antimony and lead are also frequently used in small quantities in the mixture.

Back Lash—Lost motion in moving parts, such as a screw in its nut or in the teeth of mating gears.

Back Rest—A rest for supporting slender work in turning or grinding. When the rest follows the cutting tool, it is frequently called a "follow or follower rest." Differs from a steady rest by not surrounding the work.

Backing-Off—Removing metal behind the cutting edge to relieve friction in cutting, as in taps or reamers. Now usually called "relief." Should not be confused with "clearance." See Relief and Clearance.

Balance, Dynamic or Running—Securing the proper distribution of weight so that shafts or pulleys will run without vibration.

Balance, Static or Standing—Distributing the weight of pulleys or shafts so that, when placed on knife-edge ways, they will stand in any position. If unbalanced, the heavy side rolls to the bottom.

Balancing Machine—Machine for measuring the "throw," or "out of balance" of a revolving piece and showing the amount and location of weight to be added or removed to secure a running balance.

Balancing Ways—Level strips or sharp-edged disks for testing shafts or pulleys for standing balance. The disks are usually mounted on ball bearings.

Band Saw—Continuous saw running on and driven by suitable pulleys. Originally used only for wood, is now commonly used on metals. For inside work the saw ends are put through a hole and brazed by a small electric device on the machine. One make uses a very long saw blade that is not brazed. It is pulled through the work and then returned rapidly for the next cut.

Bastard—Not regular. Seldom used except as applied to a file or thread of irregular cut or shape.

Bearing—The support in which a shaft revolves. May be plain, ball or roller. The latter interpose balls or rollers between the shaft and the support to reduce friction. Frequently called anti-friction bearings.

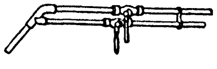
Bench, Inspection—See Inspection Bench; Laying-Out Bench; Workbench.

Bevel—Any surface not at right angles to the rest of the piece. When at 45 degrees the bevel is frequently called a miter. Name is also given to tool for measuring or laying off bevels. When combined with a scale of degrees, it is called a bevel protractor.

Blocks, Hoisting—Any combination pulleys and ropes or chains by which weights are lifted. They are usually hand operated but in some few cases employ either electric or air motors. Differential, planetary or worm gearing is used.

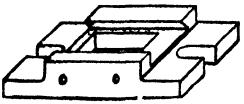
Blocks, Hoke—Gage blocks for positive measurements, designed by Major Hoke. Used for checking snap and other gages.

Blocks, "Jo"—Shop name for Johannssen measuring blocks.



Blow Pipe—A device for mixing a jet of air with a flame both to direct the flame and to increase the heat. The upper picture shows the type used with an alcohol lamp, while the lower mixes both gas and air by means of the pipes and valves shown.

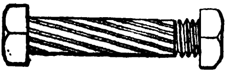
Blow Torch—A portable device for securing intense local heat. Used by plumbers and for similar work.



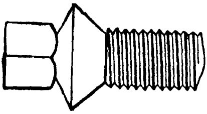
Bolster

Bolster—A block sometimes called the die block, in which a punch press die is held. It is attached to the bed by bolts at either end.

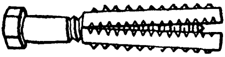
BOLTS:



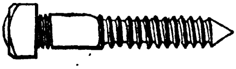
Agricultural Bolt—Agricultural bolts, as indicated by the name, are used in farm machines and appliances. The body of the bolt has a series of helical lands and grooves which are formed by a rolling process.



Boiler-Patch Bolt—A bolt used in fastening patches on boilers. The patch is countersunk for the cone head, and boiler shell tapped for bolt thread. The square head is knocked off after bolt is in place.

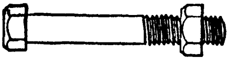


Expansion Bolt—In attaching parts to brick, stone or concrete walls and floors, expansion bolts are frequently employed. The "Star" bolt in the illustration has an internally threaded, split sleeve which is slipped into a hole made in the wall and then expanded by running in the screw.

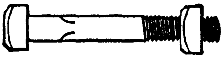


Hanger Bolt—This bolt is used for attaching hangers to woodwork and consists of a lag screw at one end with a machine bolt thread and nut at the other.

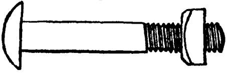
Machine Bolts



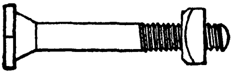
Hexagon Head



Square Head

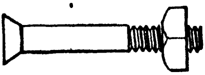


Round Head

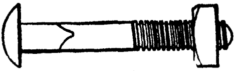


Square Countersunk Head

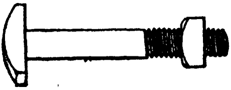
Miscellaneous Bolts



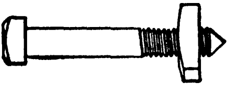
Tire



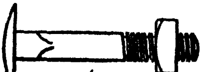
Loom or Carriage



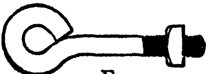
Oval T-Head



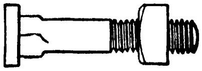
Joint



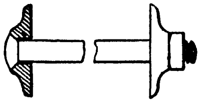
Step



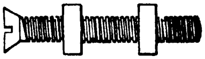
Eye



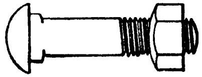
Deck



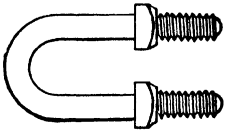
Bridge or Roof



Sink



Track



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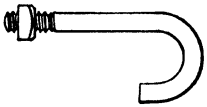
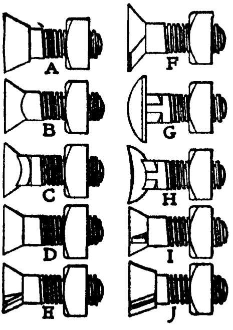
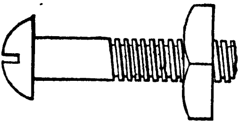


Hook



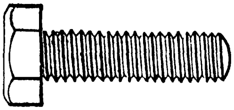
Plow Bolt—Several types of plow and cultivator bolts are shown in the accompanying engravings, the forms illustrated being typical of a variety of bolts manufactured for agricultural apparatus.

A—Large Round Head
B—Square Head
C—Round Head, Square Shank
D—Round Head
E—Key Head
F—Tee Head
G—Button Head
H—Concave Head
I—Reverse Key Head
J—Large Key Head.



Round or Button Head

Stove Bolt—Stove bolts are made in sizes ranging from ⅛ to ⅜ inch. The heads commonly formed are the round or button head, and the flat or countersunk head.



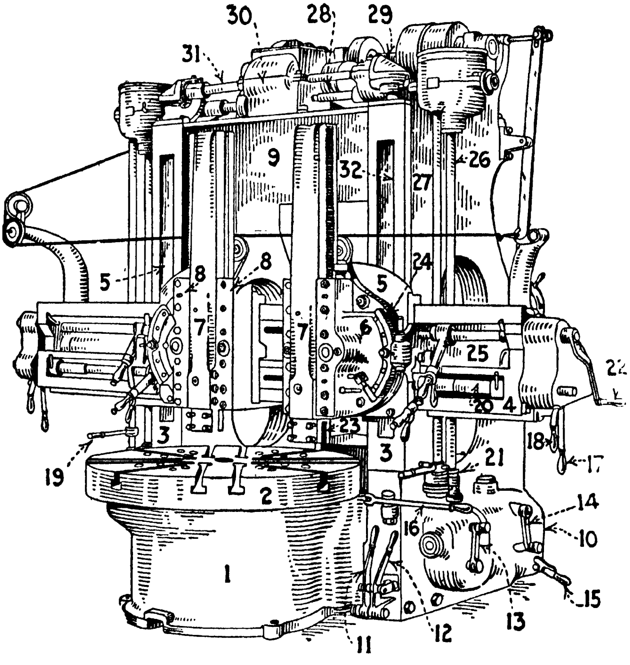
Hexagon Head Tap Bolt

Tap Bolt—Tap bolts are usually threaded the full length of the body, which is not machined prior to running on the die. Only the point and the under side of the head are finished. They are also made with square heads.

Bolt Cutter—Machine for cutting threads on bolts.

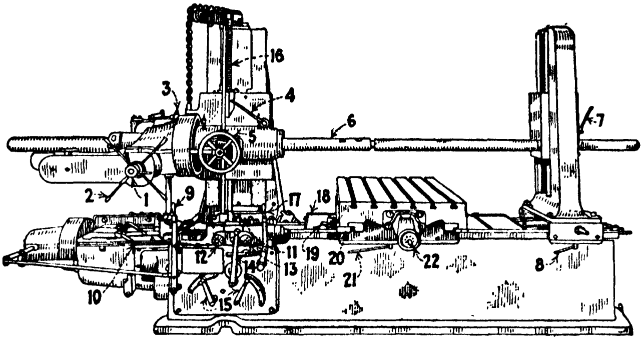
Bolt Header—Machine for upsetting the bolt body to form the head.

Boring and Turning Mill—Machine having a rotating horizontal table for the work with one or more stationary vertical tools for boring, turning or facing; a turret is often provided for holding a number of tools in one of the heads. Sometimes has a tool head on side rail. Often called "vertical mill." Horizontal boring machines are not usually called "mills."



BORING MILL, VERTICAL

1. Bed.
2. Table.
3. Housing.
4. Rail.
5. Saddle.
6. Swivel.
7. Ram.
8. Swivel clamp.
9. Arch.
10. Feed box.
11. Change gear lever.
12. Back gear lever.
13. Feed reverse lever.
14. Feed back gear lever.
15. Tumbler lever.
16. Start and stop lever.
17. Vertical feed lever.
18. Cross feed lever.
19. Rapid traverse handle.
20. Rail screw.
21. Feed clutch.
22. Crank handle.
23. Tool holder.
24. Swivel segment gear.
25. Feed rod.
26. Feed shaft.
27. Rapid traverse shaft.
28. Horizontal rapid traverse shaft.
29. Elevating gear.
30. Elevating device.
31. Elevating shaft.
32. Elevating screw.



BORING MACHINE, HORIZONTAL

1. Spindle feed clutch.
2. Quick hand spindle movement.
3. Interlocking back gear levers
4. Head locking lever.
5. Slow spindle movement.
6. Spindle.
7. Tail block clamp.
8. Back rest base clamp.
9. Power control lever.
10. Speed change levers.
11. Interlocking feed levers.
12. Hand adjustment for head, micrometer dial.
13. Hand adjustment for saddle micrometer dial.
14. Reverse lever for feed and quick return.
15. Feed change levers.
16. Head elevating screw.
17. Feed and quick return lever.
18. Removable bed guard.
19. Platen feed trip lever.
20. Limit stop to platen.
21. Saddle clamp.
22. Hand adjustment for platen, micrometer dial.

Brass—An alloy of copper with zinc and lead.

Brazing—The joining of metals by the use of copper filings or chips and borax or some other flux This is usually called spelter or hard solder and can be applied to almost any of the harder metals.

Brazing Clamps—Clamps to hold the ends of band saw or other work for brazing.

Broach—A tool which is practically a series of chisels or cutting edges for enlarging holes or changing their shape. The same name is sometimes given to a small reamer used by jewelers.

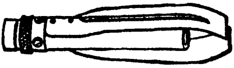
Broaching—This has become a standard method of machining both holes of any shape and outside surfaces that were formerly milled. Machines are made in horizontal, vertical, and rotary forms. Some machines closely approach milling by using rotating cutters.

Bronzes—Alloys of copper and tin. Used in coinage, bells, statuary, musical instruments, etc.

Bull Blocks—Blocks through which wire or rods are drawn to reduce size.

Bull Wheel—Usually applied to the gear of a planer which meshes into the rack under the table and drives it.

Bulldozer—Heavy forming machine for bending iron or steel and in which the dies move horizontally. Very similar to a forging press.



Bunsen Burner—A device for securing a very hot flame by mixing air and gas in a chamber behind the flame. The one shown has two side pieces which make the flame flat instead of round.

Burnishers—Tools of hardened and polished steel for finishing metals by friction. They are held against the revolving work and give a smooth surface by compressing the outer layer of the metal.

Burnishing—Finishing metal by contact with hardened surfaces that compress the surface to some extent. Largely used in railway work for crankpins and axles. Also used by some for finishing gear teeth before hardening by rolling with hardened gears. Burnishing is also done by using steel balls in tumbling barrels.

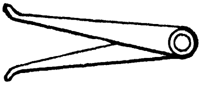
Bushing—Tube or shell supported by other material. Hardened bushings are used in jig work to guide drills or other tools. Bushings are frequently used as bearings for revolving shafts.

Butt Joint—A riveted joint with the ends of the plates abutting squarely against each other.

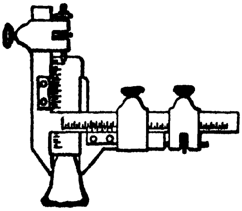
Butt Weld—A weld in which the ends of the two pieces simply abut against each other for welding together.

C

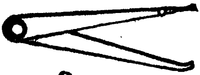
CALIPERS:



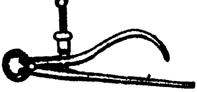
Firm-Joint Calipers—Having a large firm joint in place of old style plain riveted joint. This shows an inside caliper.



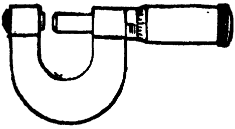
Gear-Tooth Caliper—A caliper with two beams at right angles. The vertical beam gives tooth depth to pitch line and the other the thickness at pitch line. Both have verniers. Used in measuring teeth for accuracy.



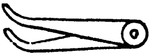
Hermaphrodite Caliper—A combination of one leg of a divider and one leg of a caliper. Used in testing centered work and in laying off distances from the edge of a piece.



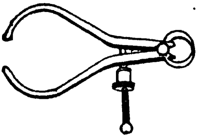
Keyhole Caliper—Has one straight leg and the other curved.



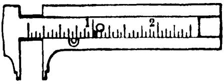
Micrometer Caliper—A measuring instrument consisting of a screw and having its barrel divided into small parts so as to measure slight degrees of rotation. Usually measures to thousandths, sometimes to ten-thousandths.



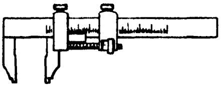
Odd-Leg Caliper—Calipers having both legs pointing in the same direction. Used in measuring shoulder distances on flat work, boring half round, boxes, etc.



Outside, Spring Caliper—Tool for measuring the outside diameter of work. Controlled by spring and threaded nut. Nuts are sometimes split or otherwise designed to allow rapid movement when desired, final adjustment being made by screw.

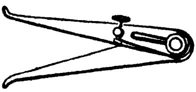


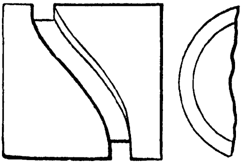
Slide Caliper—A beam caliper made with a graduated slide. Generally made small for carrying in the pocket.



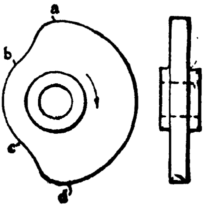
Square-micrometer Caliper—A beam caliper having jaws square with the blade,and having a vernier-micrometer adjustment to read to thousandths of an inch.

Transfer Caliper—A caliper that can be set to a given size, the auxiliary arm set, and the calipers opened at will, as they can be reset to the auxiliary arm at any time. Used to caliper recesses and places where the legs must be moved to get them out.

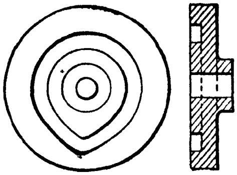




Cam, Drum or Barrel—The drum cam has a path for the roll cut around the periphery and imparts a to-and-fro motion to a slide or lever in a plane parallel to the axis of the cam. Sometimes these cams are built up of a plain drum with cam plates attached.



Cam, Edge—Edge or peripheral cams (also called "disc cams") operate a mechanism in one direction only, gravity, or a spring, being relied upon to hold the cam roll in contact with the edge of the cam. On the cam shown, *a* to *b* is the drop; *b* to *c* the dwell; *c* to *d*, rise; *d* to *a*, dwell.



Cam, Face—Face cams have a groove or roll path cut in the face and operate a lever or other mechanism positively in both directions, as the roll is always guided by the sides of the slot.

Carbide Tools—Tools with cutting points of tungsten, tantalum, or other alloy with cemented carbides. The carbide tips are brazed to high-grade steel shanks for strength and rigidity.

Carbonizing or Carburizing—The heat-treatment of steel so that the outer surface can be hardened. The surface absorbs carbon from the material used.

Case-Hardening—Former name for carburizing.

Castle or Castellated Nut—A nut with slots across the outer end to receive a cotter pin put through the bolt to prevent loosening.

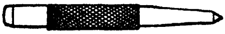
Cat Head—A collar or sleeve which fits loosely over a shaft and is clamped to it by setscrews. Used for steady rest to run on where it is not desired to run it on the work.

Same name is also given to the head carrying cutters on boring bars.

Cemented Carbide Tools—Tools made from pulverized carbides and tungsten, tantalum, or other alloys fused into a very hard tip for high-speed cutting. Next to a diamond in hardness.

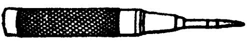
Center, Dead—The back center or the stationary center on which the work revolves. On many grinding machines both centers are dead.

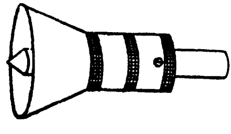
Center, Live—The center in the revolving spindle of a lathe or similar machine. It is highly important that this should run true or it will cause the work to move in an eccentric path.



Center Punch—Punch for marking points on metal. Made of steel with a sharp point and hardened. Often called a prick punch.

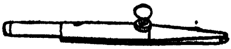
Center Punch, Automatic—Has a spring-actuated hammer in the handle, which is released when the handle is pressed way down. The point can be placed where desired and the blow given by a pressure of the hand. In some cases the blow can be varied.





Center Punch, Bell or Self-Centering—A center punch sliding in a bell or cone-mouthed casing so that when placed square over the end of any bar it will locate the center with sufficient accuracy for most purposes.

Center Punch, Locating—Having an extra leg that has a spring point and is adjustable. The spring is placed in the first punch mark and so locates the next punch mark at the right distance from the first.



Centering Machines—For drilling and reaming center of work for the lathe or grinder.

Chamber—A long recess. See Recess.

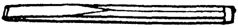
Chasers—Tools used for cutting threads by chasing. Usually have several teeth of right pitch, but name is sometimes applied to a single-point tool used in brass work on a Fox lathe. Chasers are made circular or flat. The cutting tools used in die heads.

Chasing Threads—Cutting threads by moving a single tool along the work at the right speed to give the proper pitch. Distinguishes between threads cut with a die and those cut with a threading tool.

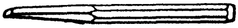
Chattering—Caused by a slight jumping of the tool away from the work, or *vice versa*, and leaves little ridges on the surface. The jumping is due to springing of the tool, work, or machine.

Chipping—The cutting of metal with cold chisel and hammer. Also used when a piece "chips" or breaks out of a piece or punch.

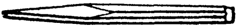
Chisel, Cape—Chisel with a narrow blade for cutting keyways and similar work.



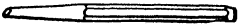
Flat Cold Chisel



Diamond



Cape



Round

Chisel, Cold—Any chisel for cutting cold metal. Name is usually applied to plain flat cold chisel, as in illustration.

Chisel, Diamond or Lozenge—Similar to a cape chisel but with square end and cutting edge at one corner. Used for cutting a sharp-bottomed groove.

Chisel, Round—A round-end chisel with the cutting edge ground back at an angle. Used for cutting oil grooves and similar work.

Chuck, Draw—Operated by moving longitudinally in a taper bearing. Used on precision work.

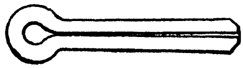
Clearance—Space allowed to prevent interference.

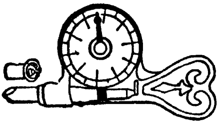
Climb Cutting—Milling with the direction of feed where the cutter tooth "climbs" or comes down on the work.

Comparator—Name given to a machine designed by James Hartness to measure screw threads and similar parts by projecting an enlarged shadow on a chart to compare the screw with the desired standard.

Coping Machine—For cutting away the flanges and corners of beams and bending the ends.

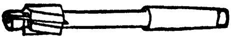
Cotter, Spring—Also called split cotter, split pin, etc. Used in a hole drilled crosswise of a stud, shaft or some similar member, and its ends spread apart to retain it in place and keep some member carried by the shaft from slipping off or turning.



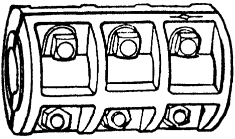


Counter, Revolution—Device for counting the revolutions of a shaft. Generally made with a worm and a gear having 100 teeth so that one turn of dial equals 100 revolutions.

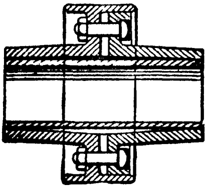
Counterbore—Has a pilot to fit a hole already drilled, or drilled and reamed, and its body with cutting edges on the end is used to enlarge the hole to receive a screw head or body or for some similar purpose.



Countershaft—An intermediate shaft, between the main drive and the final shaft or spindle. Used for starting, stopping, and reversing machinery.



Coupling, Clamp—Couplings made in two or more parts, clamping around the shafts by transverse bolts. Hold either by friction or have dowels in shaft. Sometimes called "compression" although this is confusing.



Coupling, Compression—Grips shafting by drawing together tapered parts. This forces them against shaft and holds it firmly. Bolts parallel with shaft draw parts together.

Coupling, Friction—Couplings which depend on frictional contact.

Coupling, Jaw or Clutch—Positively engaged by jaws or projections on the face of opposing parts.

Crane, Gantry—Traveling crane mounted on posts or legs for yard use. The legs travel on rails to change position.

Crane, Jib—Crane with a swinging boom or arm.

Crane, Locomotive—Crane mounted on a car with an engine so as to be self-propelling on a track.

Crane, Monorail—Traveling crane that is suspended from a single rail. Sometimes carries an operator in a suspended cage, or is operated from the floor or a central control point.

Crane, Pillar—Having the boom or moving arm fastened to pillar or post.

Crane, Portable—Hoisting frame on wheels which can be run around to the work and used to handle work in and out of lathes and other machines.

Crane, Post—See Crane, Pillar.

Crane, Traveling—Crane with a bridge or cross beam having wheels at each end so that it can be run on overhead tracks to any point in the shop.

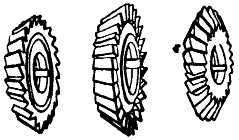
Crane, Wall—A movable crane supported by rails on a wall.

Crimping—Fluting, corrugating, or compressing metal ring to reduce its diameter.

Crossrail—The part of a planer, boring mill, or similar machine on which the tool heads or slides move and are supported.

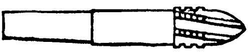
Cutters, Flue Sheet—Special cutters for making holes, as for flues, in flue sheets or in other sheet metal or structural work.

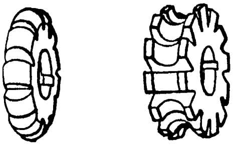
CUTTERS, MILLING:



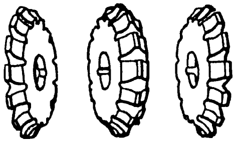
Angular Cutters—Such cutters are used for milling straight and helical mills, ratchet teeth, etc. Cutters for helical-mill grooving are commonly made with an angle of 12 degrees on one side and 40-, 48- or 53-degree angle on the other.

Cherry—A form of milling cutter which is more strictly a formed reamer, for finishing out the interior of a die or some similar tool. The cherry shown is for a bullet mold.

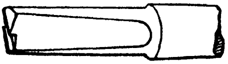




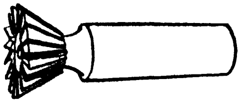
Convex and Concave Cutters—Convex and concave cutters are used for milling half circles. The convex cutter is often used for fluting taps and other tools. Like all other formed cutters the shape is not affected by the process of sharpening.



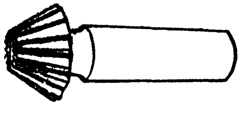
Corner-Rounding Cutters—Left-hand, double, and right-hand cutters of this type are used for finishing rounded corners and edges of work. The shape of the cutter is not altered by grinding on the face of the teeth.



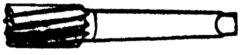
Cotter Mill—This type of mill is used for cutting keyseats and other slots and grooves.

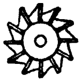


Dovetail Cutters—Inner and outer dovetails are milled with these tools, and edges of work conveniently beveled.

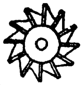


End Mill—This mill, sometimes called a "butt mill," is used for machining slots, milling edges of work, cutting cams, etc.

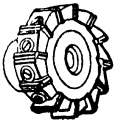




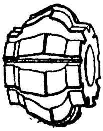
Left Hand



Right Hand



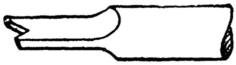
Face



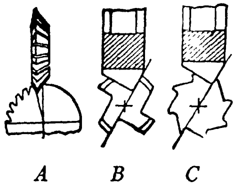
Formed

Face and Formed Cutters—The face cutter to the left, of Brown & Sharpe inserted-tooth type, is made in large sizes and cuts on the periphery and ends of teeth.

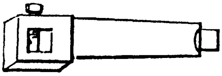
The formed cutter to the right may be sharpened by grinding on the face without changing the shape.



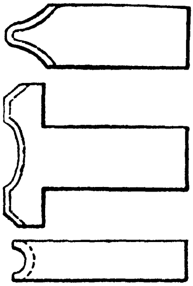
Fishtail Cutter—A simple cutter for milling a seat or groove in a shaft or other piece. Usually operated at high speed and with a light cut and feed.



Fluting Cutters—Cutter *A* is an angular mill for cutting the teeth in helical mills; cutter *B* is for tap fluting; and *C* for milling reamer flutes. In each case the cutter is shown with one face set radial to the center of the work. See End Mill.

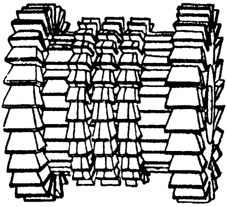


Arbor

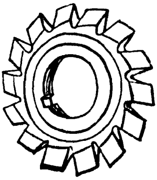


Fly Cutters—Fly cutters are simple formed cutters which may be held in an arbor like that shown at the top of the group. The arbor is placed in the miller spindle and the tool or other work to be formed is given a slow feed past the revolving cutter. After roughing out, the cutter can be held stationary and used like a planer tool for finishing the work that is fed past it and so given a scraping cut.

Fly cutters may also be simple, single point tools for boring.

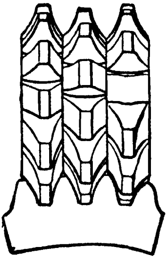


Gang Cutters—Cutters are used in a gang on an arbor for milling a broad surface of any desired form. The cutters shown have interlocking and overlapping teeth so that proper spacing may be maintained. In extensive manufacturing operation the gangs of cutters are usually kept set up on their arbor and never removed except for grinding.

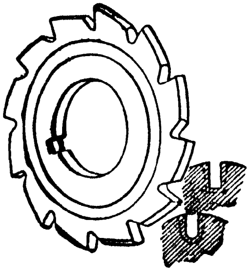


Gear Cutter (Involute)—In the Brown and Sharpe system of involute gear cutters, eight cutters are regularly made for each pitch.

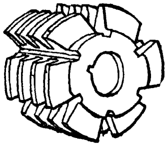
Such cutters are always accurately formed and can be sharpened without affecting the shape of the teeth.



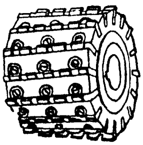
Gear Cutters, Duplex—The Gould and Eberhart duplex cutters are used in gangs of two or more; the number of cutters in the gang depending on the number of teeth in the gear to be cut.



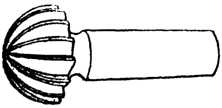
Gear Stocking Cutter—The object of stocking cutters is to rough out the teeth in gears, leaving a smaller amount of metal to be removed by the finishing cutter. They increase the accuracy with which gears may be cut, and save the finishing cutter as well.



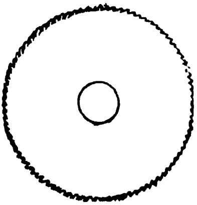
Hob—A form of milling cutter with helical teeth arranged like a thread on a screw and with flutes to give cutting edges as indicated. Used for cutting the teeth of worm, spur, helical, or herringbone gears. Hobs are formed and backed off so that the faces of the teeth may be ground without changing the shape.



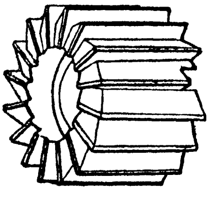
Inserted-Tooth Cutter—Inserted-tooth cutters have various devices for holding the blades in position in the bodies. Inserted-tooth construction is generally recommended for cutters 6 inches or larger in diameter.



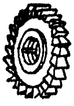
Rose Cutter—The hemispherical cutter known as a "rose mill" is one of a large variety of forms employed for working out dies and other parts in the profiler. Cutters of this form are also used for making spherical seats for ball joints, etc. Sometimes called "ball cutters."



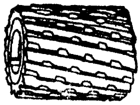
Screw-Slotting Cutter—Screw-slotting cutters have fine-pitch teeth especially adapted for the slotting of screwheads and similar work. The cutters are not ground on the sides. They are made of various thicknesses corresponding to the numbers of the American Wire Gage.



Shell-End Cutter—Shell-end mills are designed to do heavier work than that for which the regular type of end mills is suited. They are made to be used on an arbor and are secured by a screw in the end of the arbor. The end of the cutter is counterbored to receive the head of the screw and the back end is slotted for driving as indicated. Hole is tapered ⅛ inch per foot.



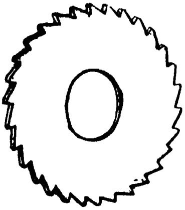
Side



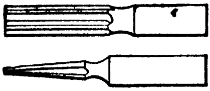
Slabbing

Side, or Straddle, and Slabbing Cutters—Side cutters like that to the left, cut on the periphery and sides, are suitable for milling slots and when used in pairs are called straddle mills. May be packed out to mill any desired width of slot or opposite faces of a piece of any thickness.

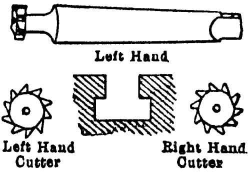
Slabbing cutters are frequently made with nicked teeth to break up the chip and so give an easier cut than would be possible with a plain tooth.



Slitting Saw, Metal—Metal slitting saws are thin milling cutters. The sides are finished true by grinding, and a little thicker at the outside edge than near the center for proper clearance. Coarse teeth are best adapted for brass work and deep slots and fine teeth for cutting thin metal.



Straight-Shank Cutter—Straight-shank cutters of small size are extensively used in profilers and vertical millers for die sinking, profiling, routing, etc. They are held in spring chucks or collets.



T-Slot Cutter—Slots for bolts in miller and other tables are milled with T-slot cutters. They are made to standard dimensions to suit bolts of various sizes. The narrow part of the slot is first milled in the casting, then the bottom portion is widened out with the T-slot cutter.

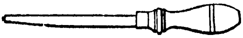
D

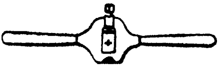
Derrick—Structure consisting of a fixed upright and an arm hinged at bottom, which is raised and lowered and usually swings around to handle heavy loads.

Dial Feed—A revolving disk which carries blanks to the punch and die, or to other tools.

Diamond Boring—Boring accurate holes with a diamond as the cutting point. Term is also used for any accurate boring with a single-point tool of carbide or other material.

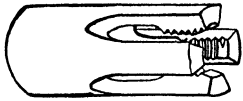
Diamond Hand Tool—Used for dressing grinding wheels after they have been roughed out with the cheaper forms of cutters. Fixed diamonds are usually considered better than those held by hand.





Die, Screw Plate or Stock—A frame or handle for holding a threading die. Sometimes die and handles are of one piece.

Die Sets—Holders for punches and dies that are held in alignment by guides, or leader pins, and hardened bushings independently of the press itself. Formerly called "subpress dies."

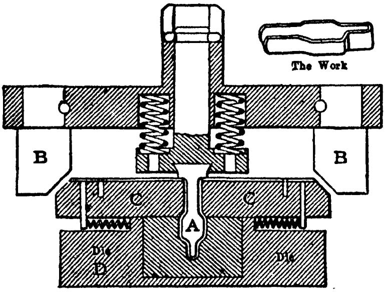


Die, Spring or Prong—Die with cutting portions in the end of prongs; can be adjusted somewhat by springing prongs together with a collar on outside.

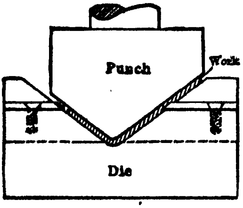
Die Chasers—Threaded sections inserted in a die head for cutting bolts and screws.

Dies, Bolt—Dies for cutting bolts. Some are solid, others adjustable. Some are for hand-die stocks or plates, but most of them are for machine bolt cutters.

DIES, PUNCH PRESS:

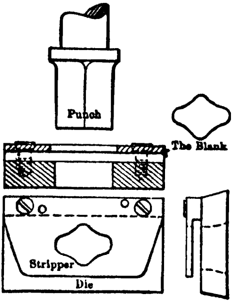


Bending Dies, Compound—In compound bending dies of the type shown, the work is carried down into the die by punch *A*, and held there while the beveled fingers *B* act upon the slides *C* and cause them to move forward in the top of die *D* and bend the material to the outline of the punch. Upon the upstroke of the punch the slides *C* are pressed outwardly by their springs and the bent piece of work is removed by the punch from the die. It will be seen that the holder for punch *A*, upon which depends the interior form of the piece being bent, is not positively secured in its holder, but is instead adapted to slide up and down in its seat although prevented from turning by a small pin at the upper end of the shank which is engaged by a slot in the punch carrier. The springs shown above the punch proper tend to hold the punch in its lower position and at the same time, after the punch has passed down into the die, allow the punch carrier to descend still further to press fingers *B* into operation against slides *C*, which bend the work to the outline of the punch.

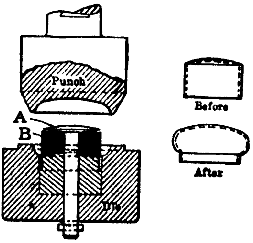


Bending Dies, Plain—Simple bending dies are made with the upper face of the die and the bottom of the punch shaped to conform to the bend it is desired to give the blank.

In simple bending dies the upper face of the die is cut out to the desired form and the piece of work formed to required shape by being pressed directly down into the die by the punch.



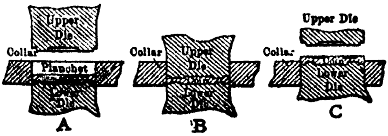
Blanking Dies—Blanking dies are about the most commonly used of all the varieties of press tools. A simple form of die is seen in the illustration. The strip of sheet metal is fed under the stripper and is prevented by that member from lifting with the punch upon the upstroke, following the punching out of the blank. Where several punches are combined in one hole for blanking as many pieces simultaneously, they are known as "multiple blanking tools."



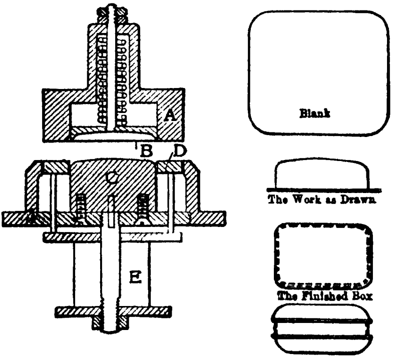
Bulging Dies—The "before and after" sketches show the character of the work handled in bulging dies. The shell, after being drawn up straight, is placed over mushroom plunger *A* in the bulging die, and when the punch descends the rubber disk *B* is forced out, expanding the shell into the curved chamber formed by the punch and die. Upon the punch ascending, the rubber returns to its original form and the expanded work is then removed.

Burnishing Dies—Burnishing dies are made a little smaller at the bottom than at the top and when the work is forced down through the die, the edge of the piece is given a very high finish making polishing and hand-finishing operations unnecessary. The burnishing process also forms a very accurate method of sizing work.

Coining Dies—Coining dies are operated in very powerful presses of the embossing type similar to those used for forming designs on silverware, medals, jewelry, etc. The position of the work, the retaining collar, and the dies are indicated at *A*, *B*, and *C*. In the last section the coin is shown delivered at the top of the die.



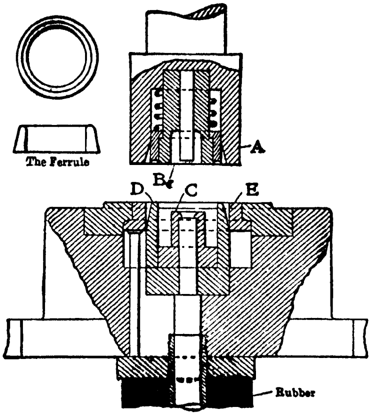
Combination Dies—Combination dies are used in single-acting presses for such work as cutting a blank and at the same stroke turning down the edge and drawing the piece into the required shape. In most cases the work is pushed out of the dies by the action of a spring. Such a set of dies is shown in the engraving, for making a box cover and body. The work is blanked by cutting punch *A*, and formed to the right shape by *B* and *C*, the former holding the piece by spring pressure to the block *C* while punch *A*, continuing to descend, draws the box to the required shape. Ring *D* acts as an ejector, or shedder, and is pressed down, compressing the rubber at *E* during the drawing operation, and upon the upstroke of the punch, ascends and ejects the work from the dies.



Dies of this type, with a spring-actuated punch or die inside the regular blanking tool, are often used for simultaneously blanking and piercing, blanking and bending, etc.

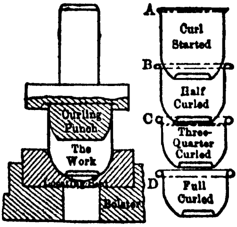
It will be noticed that the lower view in the group, showing the work at the right-hand side of the sectional illustration of the die, represents the box cover and body as they appear when assembled after the superfluous metal in the flange or "fin," has been removed in a trimming die. This fin, as left on the piece when coming from the combination die, is shown in the view immediately under the blank. For a die to finish such work evenly, see Trimming Die.

Compound Dies—Compound dies have a die in the upper punch and a punch in the lower die. The ferrule-making tools shown have a blanking and outer drawing punch *A*, with a central die *B*, to receive lower punch *C* which cuts out the center of the ferrule blank and allows the metal to be drawn down inside as well as outside of the bevel-edged member *D*. As the work is drawn down, ring *E* descends compressing the rubber cushion below, and upon the return movement, the ferrule is ejected from the die.

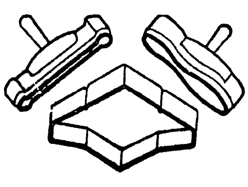


Cupping Dies—Used for drawing up a cup from a disc or planchet. Same as drawing dies.

Curling Dies—Curling dies are used for producing a curled edge around the top of a piece drawn up from sheet metal. When the top is to be stiffened by a wire ring around which the metal is curled, a wiring die is used, the construction of which is practically the same as that of the curling die. The illustration shows a curling die and the appearance of a shell at various stages during the operation of curling over the edge. The diagrams, *A*, *B*, *C*, *D*, show the progress in the curling process as the punch descends, pressing down on the edge of the straight-drawn shell.

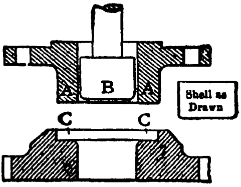


Dinking Dies—Dinking dies, or hollow cutters, although not usually classed with regular dies, are used so commonly as to entitle them to be listed in that class. They are adapted to punching out all sorts of shapes from leather, cloth, or paper. The edges of the dies (a few specimens of which are shown in the engraving) are usually beveled about 20 degrees outside. Where made for press use, the handle is omitted. As a surface

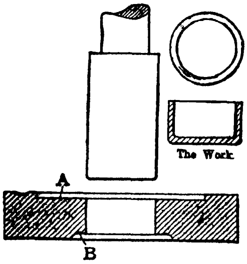


for the cutting edge of the die stroke on, a block is built up of seasoned rock maple, set endwise of the grain.

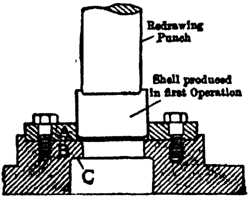
Double-Action Dies—This type of die is used in a press which has a double-acting ram; that is, there are two slides, one inside the other, which have different strokes. To the outer slide is fastened the combined cutting punch and blank holder *A*, which is operated slightly in advance of the drawing punch *B* actuated by the inner slide. The blank upon being cut from the stock by *A*, drops into the top of the die at *C* and is kept under pressure by the flat end of cutting punch *A* to prevent its wrinkling, while punch *B* continues downward drawing the metal from between the pressure surfaces and in the shape required.



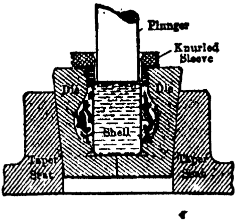
Drawing Dies, Plain—Dies of the type shown can be used for shallow drawing only, as there is no pressure on the blank to prevent its wrinkling when forced down into the die by the punch. The blank fits the recess *A* in the upper face of the die and the die itself which is slightly tapering is made the diameter of the punch plus twice the thickness of the wall required for the shell. The bottom edge *B* of the die strips the shell from the punch when the latter ascends.



Redrawing dies are used for drawing out a shell or cup already formed from the sheet metal. In the illustration, a shell ready for redrawing is shown in position in the dies, which need little explanation. The work is located in the upper plate *A*, and after being forced through the die *B*, is stripped from the punch by edge *C*. Ordinarily a shell, that is to be given considerable elongation, is passed through a number of redrawing dies.

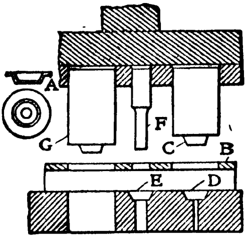


Redrawing dies are sometimes referred to as reducing dies, although the latter are used for drawing down the end of a shell only, as in the case of a cartridge shell, which is made with a neck somewhat smaller in diameter than the body.

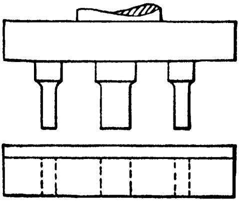


Fluid Dies—Water or fluid dies are used for forming artistic hollow ware of silver, and other soft metals, in exact reproduction of chased work. The die as shown is a hinged mold cast from carved models and finished with all details clean and sharp. The shell to be worked is filled with liquid and enclosed in the die and a plunger in the press ram then descends and causes the fluid to force the metal out into the design in the die.

Follow Dies—Follow tools consist of two or more punches and dies in one punch holder and die body, these being arranged in tandem fashion so that after the first operation the stock is fed to the next point and a second operation performed; and so on. In the die shown, which is for making piece *A*, the strip of metal is first entered beneath stripper *B* far enough to allow the first shell to be drawn at the first stroke by punch *C* and die *D*. The metal is then moved along one space and the shell drawn at the first stroke is centered and located within the locating portion of piercing die *E*. At the next stroke the hole in the center is pierced with punch *F*, and a second shell drawn in the stock by punch and die *C* and *D*. The stock is then fed forward another space and the blanking punch *G* cuts out the piece from the metal. At the same stroke a third piece is being formed on the end of the stock and a second hole pierced. Thus three operations are carried on simultaneously.



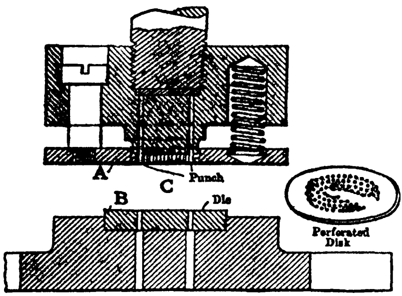
Gang Dies—Gang tools have two or more punches and dies in one holder for making as many openings in a blank at one stroke of the press. Sometimes dies which perform a number of operations on a piece which is fed along successively under one punch after another are called "gang" dies; strictly speaking, however, such tools are "follow" dies. Where a large number of punches are combined they are called a multiple punch, or if they are of quite small diameter for piercing are sometimes known as perforating punches.



Heading Dies—Heading dies strike up the heads on cartridges and other shells and are generally operated in a horizontal heading machine.

Index Dies—For certain classes of work, such as notching the edges of large discs or armature punchings, an index die is sometimes used consisting of a rotary index plate adapted to carry the work, step by step, past the punches which cut out one notch or a series of notches at each stroke of the press.

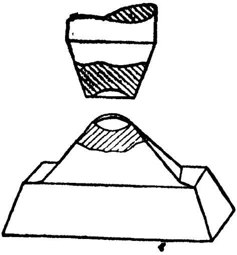
Perforating Dies—Perforating tools consist of a number of piercing tools in one set of dies and may be called also "multiple piercing tools." In the example shown, which punches a large number of holes in a disc, the work is held by the spring-controlled pressure-pad *A* against the face of the die *B* while the punches at *C* are forced down through the sheet metal. In this case the punches are easily replaced when broken by unscrewing the holder from the shank and slipping the small punch out from the back.



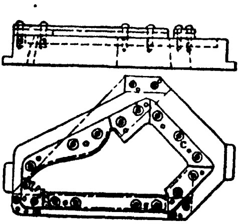
Piercing Dies—Piercing tools are used for punching small holes through sheet metal. Where arranged for punching a large number of holes simultaneously, they are often called "perforating dies."

Piercing Dies, Compound—Compound piercing tools have, in addition to the regular punches carried by the holder in the ram, a set of horizontal punches for making holes through the sides of the work. These side punches are operated by slides moved inward by wedge-shaped fingers, the arrangement being the same as in the case of the compound bending dies, an illustration of which is given under that head.

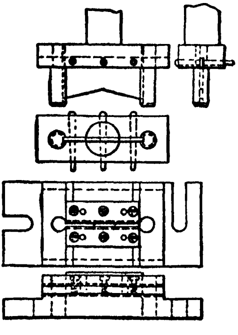
Reducing Dies—Reducing dies are redrawing dies for reducing a portion of the shell only, whereas the regular redrawing die reduces the whole length. Reducing dies for cartridge shells form the familiar "bottle neck" shell now so commonly manufactured, with a large body for the powder and a smaller neck into which the bullet is secured. In dial-feed presses ordinarily employed for cartridge-making operations, two or more reducing dies are often used for shaping the neck of the shell to the required dimensions, each die operating in turn upon the shell as it is carried around step by step under the press tools by the intermittent rotary movement of the feeding dial.



Riveting Dies—Riveting dies for the punch press are provided with cavities in the working faces to suit the shape of the head it is desired to produce on the ends of the rivets.



Sectional Dies— Frequently dies of complicated outline are built up in sections to enable them to be more easily constructed and kept in order. This form is resorted to often in the case of large dies where a break at one point would mean considerable expense for a new die. Also the difficulties of hardening are reduced with the sectional construction. As shown, the various parts are secured to a common base or holder.



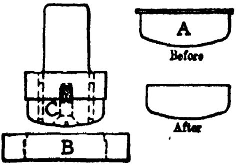
Shearing Dies—Shearing dies are used for cutting-off operations, and are frequently combined with other press tools so that after certain operations on a piece it can be severed from the end of the stock. The shearing tools in the engraving are arranged for simply cutting up stock into pieces of the required length and the punch itself is of the inserted type secured by pins in its holder.

Split Dies—Split dies form one type of sectional die—the simplest; they are made in halves to facilitate working out to shape, hardening, and economical maintenance.

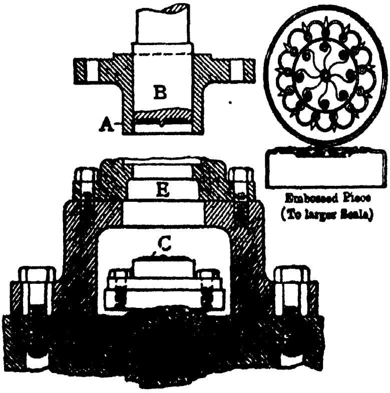
Subpress Dies—Units that hold punches and dies in alignment without depending on the press in which they are used. These are now called "die sets."

Swaging Dies—Swaging operations are resorted to where it is desired to shape up or round over the edges of work already blanked out. Thus in watch wheel work the arms and inside edges of the rims are sometimes swaged to a nicely rounded form subsequent to the blanking out of the wheel in the subpress. Swaging dies for such work are of course made with shallow impressions which correspond to a split mold between the two halves of which the blank is properly shaped.

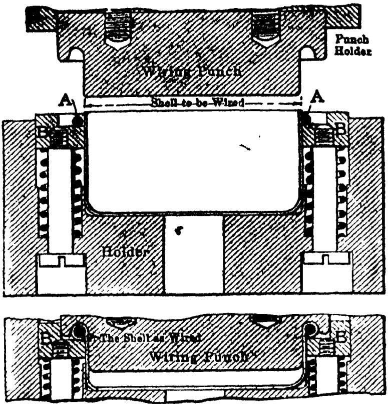
Bullet swaging dies receive the slug as it comes from the bullet mold and shape the end to the required cone point.



Trimming Dies—Trimming dies remove the superfluous metal left around the edges or ends of various classes of drawn and formed work. In the case shown, the box body *A* has been drawn up and a fin left all the way round; this is dropped into the trimming die *B*, and the punch *C*, in carrying it through the die, trims the edge off evenly, as indicated. Work of the nature shown in this illustration is blanked, drawn up, and formed ready for trimming by means of combination tools. The box body illustrated here as it appears before and after trimming is shown in connection with the combination dies as it appears in the blank, after it is formed, and after assembling with its cover.

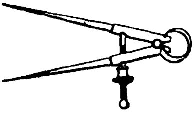


Triple-Action Dies—These dies are used in triple-acting presses, where in addition to the double-action slides which take the place of the regular single-acting ram, there is also a third slide or plunger which operates under the table or die bed. Thus a piece like that shown, which has to be blanked, drawn, and embossed, is operated upon from above by the cutting and drawing punches *A* and *B*, and upon the latter carrying the drawn work down to the face of the embossing die *C*, that die is forced upward by the plunger *D* beneath and gives the piece the desired impression. On the upstroke of the punch the work is stripped from it by edge *E* and falls out of the press.



Wiring Dies—Wiring dies are much the same in construction as plain curling dies. In the engraving, the wire ring is shown at *A* around the top of the shell to be wired and in a channel at the top of the spring-supported ring *B*. As indicated in the lower illustration, the punch, as it descends, depresses the ring *B* and curls the edge of the shell around the wire ring *A*.

Disks, Reference—Accurate disks of standard dimensions for setting calipers and measuring. Usually of hardened steel.

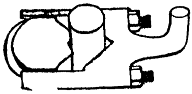


Divider, Spring—The spring tends to force the points apart and adjustments are made by the knurled nut on the screw.

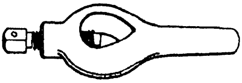
Doctor—Local term for adjuster or adapter so that chucks from one lathe can be used on another. Sometimes used in the same way as the term "dutchman."

Dog—Name given to any projecting piece which strikes and moves some other part, as the reversing dogs or stops on a planer or milling machine. Sometimes applied to the pawl of a ratchet.

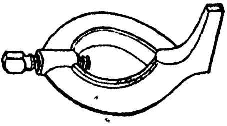
Dog, Lathe—A device for clamping work so that it can be revolved by faceplate. Three are shown.



Clamp Dog



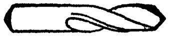
Straight Tail



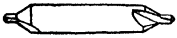
Bent Tail

Drift—A tool for cutting out the sides of an opening while driven through with a hammer. Term sometimes applied to a taper pin for forcing holes into alignment, as in boiler work.

DRILLS:



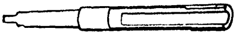
Drill



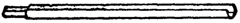
Combination

Center Drill—The short drills used for centering shafts before facing and turning are called "center drills." The drill and reamer or countersink for the 60-degree center hole, when combined as shown, allow the centering to be done more readily than when separate tools are used.

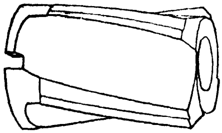
Core Drill—The core drill is a hollow tool that cuts out a core instead of removing the metal in the form of chips. Such drills are generally used to procure a core from the center of castings or forgings for the determination of the tensile strength or other physical properties of the metal.



Gun-Barrel Drill—Gun-barrel drills are run at high speed and under very light feed, oil under heavy pressure being forced through a hole in the drill to clear the chips and cool the cutting point and work. The drill itself is short and fastened to a shank of suitable length.

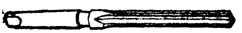


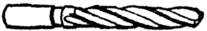
Hog-Nose Drill—More like a boring tool. Mostly used for boring out cored holes. Must be very stiff to be effective.



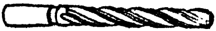
Shell Drill—Shell drills are fitted to a taper shank and used for chucking out cored holes and enlarging holes drilled with a two-flute twist drill. The angle of the lips is about 15 degrees.

Straight-Flute Drill—The straight-flute, or "Farmer," drill, as it is frequently called after its inventor, does not clear itself so well as the twist drill does, but is stiffer, and does not "run" or follow blowholes or soft spots so readily as the twist drill.





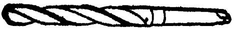
Three Groove

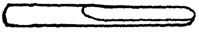


Four Groove

Three- and Four-Groove Drills—Where large holes are to be made in solid stock, it is advisable to use a three- or four-groove drill after running the required two-flute drill through the piece. These drills will enlarge the hole to the size required and are also useful in boring out cored holes in castings.

Twist Drill—Usually made with two flutes, or grooves, running around the body. This furnishes cutting edges and the chips follow the flutes out of the hole being drilled.

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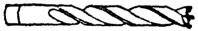
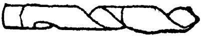
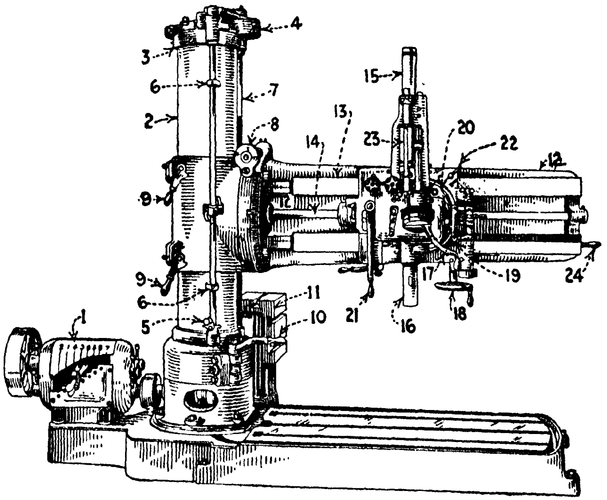

Bit Point


Single Flute

Wood Drill (Bit)—Bits for wood drilling are made in various forms. The pod drill is cut out hollow at the working end; the double-flute drill has a regular bit point; the single-flute drill is full diameter for a short distance only and is cleared the rest of the length as indicated.

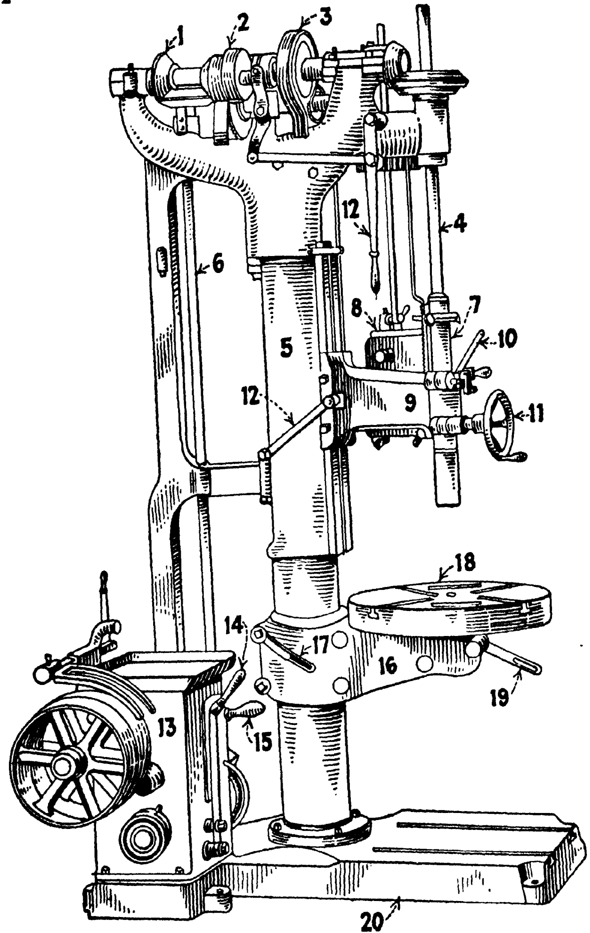
Drill, Chain—Device to be used in connection with a brace or breast drill in many places where it is not convenient to bring a ratchet drill into use.

Drill Speeder—Device which goes on drill spindle and gears up the speed of drills so that small drills can be used economically on large drill presses or boring machines.



DRILLING MACHINE, RADIAL

1. Speed box.
2. Column.
3. Column cap.
4. Elevating gearing.
5. Elevating control.
6. Elevating stops.
7. Elevating screw.
8. Arm worm box.
9. Arm clamps on column.
10. Column clamp in base.
11. Table.
12. Arm.
13. Arm way.
14. Drive shaft for head.
15. Spindle sleeve.
16. Spindle.
17. Quick spindle adjustment.
18. Hand wheel for moving head on arm.
19. Hand feed wheel.
20. Swivel gear for head.
21. Spindle control lever.
22. Head clamp on arm.
23. Feed depth gage.
24. Arm handle.



DRILLING MACHINE, VERTICAL

1. Bevel driving gears.
2. Friction clutch.
3. Back gears.
4. Spindle.
5. Column.
6. Drive shaft.
7. Spindle sleeve.
8. Feed box.
9. Head.
10. Quick-return lever.
11. Hand feed wheel.
12. Head clamp.
13. Speed box.
14. Starting lever.
15. Tumbler gear lever.
16. Table arm.
17. Table arm clamp.
18. Table.
19. Table clamp.
20. Base.

Dutchman—Local term for a wedge or liner to make a piece fit. Used to make a poor job usable. A round key or pin fitting endwise in a hole drilled half in a shaft and half in the piece to be attached thereto. A patch fitted to cover defect.

E

Ejector—An ejector on punch press work is a ring, collar, or disk actuated by spring pressure or by pressure of a rubber disk, to remove blanks from the interior of compound and other dies. It is often called a shedder.

End Measuring Rod—Arranged for internal measurements similar to the internal cylindrical gages. Also used in setting work-tables on boring machines and jig borers.

Expansion Fit—The reverse of a shrink fit. Instead of expanding the outer member by heat, the inner member is contracted by dry ice, or other freezing method before assembling. See Shrink Fit.

Extractor, Oil—Machine for extracting oil from iron and metal chips. Revolves rapidly and throws out the oil by centrifugal force.

F

Faceplate—The plate or disc that screws on the nose of a lathe or other machine spindle and drives or carries work to be turned or bored. Sometimes applied to table of vertical boring mill.

Feather—A sliding key—sometimes called a spline. Used to prevent a pulley, gear, or other part from turning on the shaft but allows it to move lengthwise as in the feed shaft used on most lathes and other tools. The feather is nearly always fastened to the sliding piece.

Filing Machine—Runs a file by power, usually vertically. Useful in many kinds of small work. Now made continuous.

Fin—The thin edge or mark left by the parting of a mold or die. In drop forge work this is called the "flash."

Flash—Excess metal forced out between the dies in drop forgings or in die castings.

Flute—Shop name for a groove. Applied to taps, reamers, drills and other tools.

Flywheel—Heavy wheel for steadying motion of machinery. On an engine it carries the crank past the center and produces a uniform rotation.

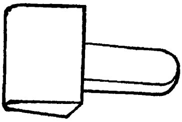
Foot Stock—The tail stock or tail block of a lathe, grinder, etc.

Force—A master punch which is used under a powerful press to form an impression in a die. Forces are commonly employed in the making of coining and other embossing dies. A similar tool used by jewelers is called a "hub" It is sometimes referred to as a "hob."

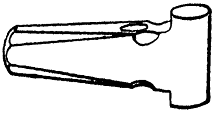
Forge—Open fireplace for heating metals for welding, forging, etc. Has forced draft by fan or bellows.

Forging Press—Heavy machine for shaping metal by forcing into dies by a steady pressure instead of a sudden blow as in drop forging. Similar to a bulldozer.

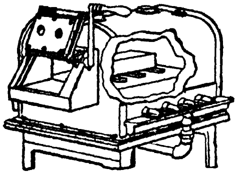
Fuller—Blacksmith's tool something like a hammer, having a round nose for spreading or fulling the iron under hammer blowers.



Anvil Fuller



Hand Fuller

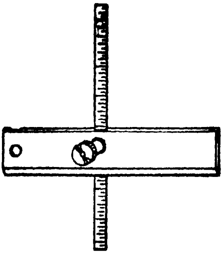


Furnace, Muffle—Furnace for heating steel to harden, in which the flame does not come in contact with the metals.

Furniture—In machine shops applies to tool racks, lathe pans, tote boxes, angles, blocking, clamps and bolts.

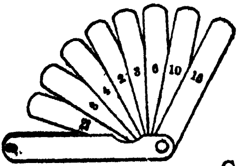
G

GAGES:

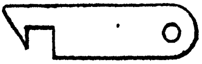


Depth Gage—A tool for measuring the depth of holes or recesses. The body is placed across the hole while the rule is slipped down into the hole to be measured. In many cases the rod is simply a wire and not graduated.

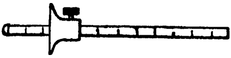
Drill Gage—A flat steel plate drilled with different-sized holes and each marked with correct size or number. Or a plate with a tapered slot, graduated to show size of drill placed in the opening.



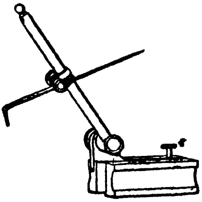
Feeler or Thickness Gage—Blades of different thicknesses, usually varying by thousandths of an inch, so that slight variations can be felt or measured.



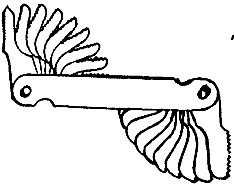
Gear-Tooth Depth Gage—A gage for measuring the depth of gear teeth. Requires a different gage for each pitch.



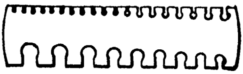
Scratch Gage—For scratching a line at a given distance from one side of a piece. Adjustable for different lengths.



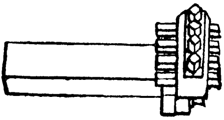
Surface Gage—A tool for gaging the height between a flat surface, such as a planer table or a surface plate, and some point on the work. This can then be transferred to any other point.



Thread Gage—Tool with a number of blades, each having the same number of notches per inch as the thread it represents. Made for different kinds of threads and in various forms.



Wire Gage—Gage for measuring sizes of wire. The wire fits between the sides of the opening, not in the holes. Sometimes made in the form of a circular disk.

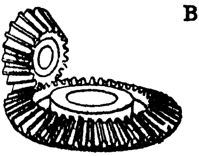


Gang Tool—A holder with a number of tools, generally used in the planer but sometimes in the lathe. Each tool cuts a little deeper than the one ahead of it.

GEARS:

Angular Gear—Sometimes applied to bevel gears and also to spur gears with helical or skew teeth. See those terms.

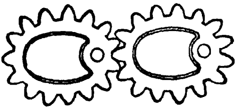
Annular Gear—Toothed ring for use in universal chucks and similar places. Teeth can be on any of the four faces, although when inside it is usually called an internal gear. The annular gear that drives the axle of an automobile is often called a "ring" gear. Gears on flywheels are called "starter" gears.



Bevel Gears—Gears cut on conical surfaces to transmit power with shafts at an angle to each other. When made for shafts at right angles and with both gears of the same size are often called "miter" gears. Teeth may be either straight, skew, or curved. These are called spiral-bevel.

Crown Gear—A gear with teeth on the side of rim. Used before facilities for cutting bevel gears existed. Seldom found now.

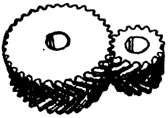
Differential Gearing—Where two gears, side by side but on different shafts, one having a few less teeth than the other, mesh into the same gear, each driving its shaft at a different rate. There is usually only one or two teeth difference in the two gears.



Elliptical or Eccentric Gears—Gears in which the shaft is not in the center. May be of almost any shape, oval, heart shaped, etc. Printing presses usually have good examples of this.

Gear Shaping Machines—The cutting of spur gears by the shaping method is confined to the Fellows and Sykes machines. The Fellows and Sykes uses a round cutter that is virtually a gear while the Maag uses a straight cutter that is equivalent to a section of a rack. Although the machines and methods of indexing are quite different, they cut the teeth by the shaping or planing process. Directions for operating are given by the makers.

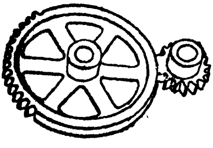
Helical Gears—Gears having teeth at an angle across the face to give a more constant pull. Also give side thrust. Sometimes called "skew" gears or spiral gears.



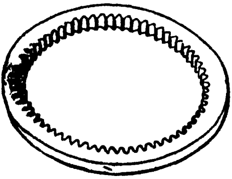
Herringbone Gears—Gears having teeth cut at opposite angles. Also made by putting two helical or "skew"-tooth gears together. Does away with side or end thrust.

Hobbing Gears—In cutting gears by the hobbing process it is necessary that both the hob and the gear blank revolve in proper relation to each other. The spindle carrying the hob must be set to the right angle to give the gear tooth desired. For cutting spur gears, the thread of the hob must be parallel with the axis of the gear. For cutting helical gears, the thread of the hob must be set parallel with the angle of the gear teeth. Then the right gearing must be selected to rotate the hob and work the spindles in the correct relation. Directions for doing this are given by the makers of hobbing machines.

Hypoid Gears—Spiral-bevel gears in which the pinion is above or below the center of the gear.



Intermittent Gears—Gears where the teeth are not continuous but have plain surfaces between. On the driven gear these plain surfaces are concave to fit the plain surface of the driver, and the driven wheel is stationary while the plain surfaces are in contact.



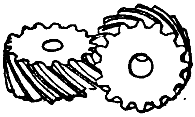
Internal Gears—Gears having teeth on the inside of a ring or shell.

Module or Metric Gears—French system of making gears with metric measurement. Pitch diameter in millimeters divided by the number of teeth in the gear is the module.

Pin Gear—Gear with teeth formed by pins such as the old lantern pinion. Also formed by short projecting pins or knobs and only used now in some feeding devices.

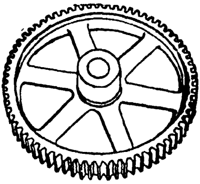
Planetary Gears—Gears mounted so as to run around a central gear, which may be either external or internal as in a Model T Ford transmission.

Quill Gears—Gears or pinions cut on a quill or sleeve.



Spiral Gears—Spur gears with helical teeth which run together at an angle and do the work of bevel gears. They are not really spiral gears but have been so designated in shop language.

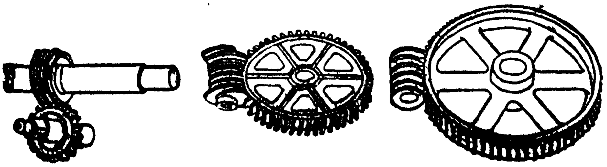
Spiral Bevel Gears—Spiral, or curved tooth, bevel gears are cut with a cutter head of the trepanning type on a Gleason machine. The methods of setting the work and cutters, and of gearing the machine, are given by the makers of the machine.

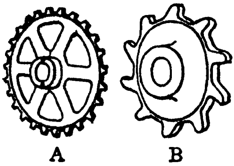


Spur Gears—Wheels or cylinders whose shafts are parallel, having teeth across the face. Teeth can be straight, helical or skew, or herringbone.

Staggered Tooth Gears—Made up of two or more straight-tooth spur gears, teeth set so that teeth and spaces break joints. Seldom used now as helical gears give smoother action.

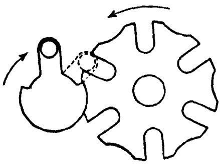
Worm Gears—Gears with teeth cut on angle to be driven by a worm. Teeth are usually cut out with a hob to fit the worm.





Sprocket Gears—Toothed wheels for chain driving. *A* is the regular tooth and *B* is a hook tooth for running one way only.

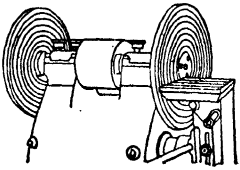
Zerol Bevel Gears.—A curved tooth bevel gear with a zero-degree spiral angle.



Geneva Motion—A device which gives a positive but intermittent motion to the driven wheel but prevents its moving in either direction without the driver. The driver may have one tooth as shown or a number if desired. Also made so as to prevent a complete revolution of the driven wheel.

Gib—A piece located alongside a sliding member to take up wear.

Gland—A cylindrical piece enveloping a stem and used in a stuffing box to make a tight joint.



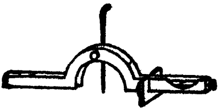
Grinder, Disc—A grinding machine having steel discs that are covered with abrasive cloth. Some discs have spiral grooves to give cushions under the abrasive cloth.

Grinder-Wheel Dresser—A tool consisting of pointed or corrugated discs of hard metal that really break or pry off small particles of the grinding wheel when held against its rapidly revolving surface. Small abrasive wheels are also used.

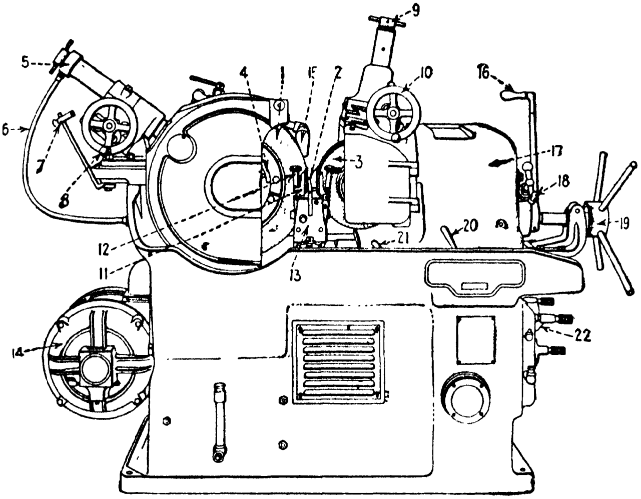
Gripe—Local name for machine clamp.

Ground Joint—A joint finished by grinding the two parts together with oil and loose abrasives.

Gudgeon—Local name for a trunnion or bearing which projects from a piece, such as a cannon.

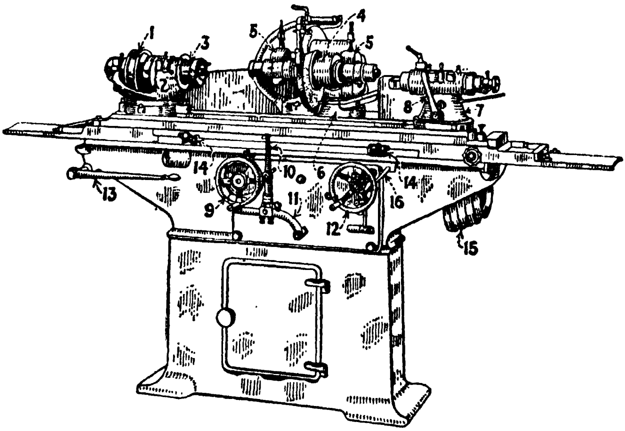


Guide Liner—A tool for use in locomotive work for lining up guides and crossheads.



CENTERLESS GRINDER

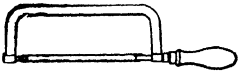
1. Grinding wheel.
2. Work-rest blade.
3. Regulating wheel.
4. Balancing-wheel collet.
5. Grinding-wheel truing attachment.
6. Coolant-line grinding-wheel truing attachment.
7. Indicator stand.
8. Hand-feed wheel for grinding-wheel truing attachment.
9. Regulating-wheel truing attachment.
10. Hand-feed wheel for regulating-wheel truing attachment.
11. Work-rest guide.
12. Work-rest guide adjusting screw.
13. Work rest.
14. Motor.
15. Coolant nozzle.
16. In-feed lever.
17. Upper slide for regulating wheel.
18. Micrometer adjustment for in-feeding.
19. Regulating-wheel in-feed screw.
20. Upper-slide clamping lever.
21. Lower-slide clamping lever.
22. Regulating-wheel speed-change levers.



UNIVERSAL GRINDING MACHINE

1. Live spindle driving pulley.
2. Headstock.
3. Dead center pulley.
4. Wheel driving pulley.
5. Spindle-box.
6. Wheel stand platen.
7. Footstock.
8. Clamping lever.
9. Cross-feed hand wheel.
10. Reversing lever.
11. Feed roll lever.
12. Table hand wheel.
13. Control lever.
14. Table dogs.
15. Feed driving cone.
16. Table hand wheel throw-out lever.

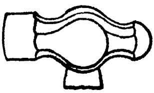
H



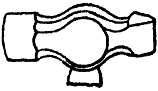
Hacksaw—Fine-toothed saw for cutting metal. Saws are held in a hand frame or in power-driven machines.

Half Nut—A nut that is split lengthwise. Sometimes half is used and rides on screw; in others, both halves clamp around screw as in the half nut of a lathe carriage.

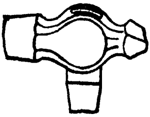
Hammer—The common types of machinists' hammers are the ball peen, straight peen, and cross peen, as shown. The so-called engineers' and the riveting hammers have cross peens.



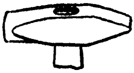
Ball Peen



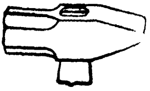
Straight Peen



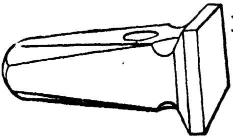
Cross Peen



Riveting



Engineers'



Hammer, Blacksmiths' Flatter—A flat-faced hammer used to smooth the surfaces of forgings. Is held on the work and struck by a helper with a sledge.

Hammer, Bumping or Horning—For closing seams on large cans, buckets, etc.

Hammer, Drop—Hammer head or "monkey" or "drop" is raised by hand or power and falls by gravity. Sometimes raised by a board attached to top of hammer head and running between pulleys. Others use a belt.

Hammer, Helve—Power hammer in which there is an arm pivoted in the center and power applied at the back end while the hammer is at the other and strikes the work on an anvil.

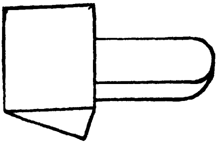
Hammer, Lever Trip—Trips the hammer by a cam or lever and allows it to fall.

Hammer, Spring—Comparatively small hammer giving a great variety in the force of blow. This is controlled by pressure of foot on lever.

Hand Wheels, Clutched—Hand wheels connected to shaft by a clutch which can be thrown out by a knob or otherwise so that accidental movement of wheel will not disturb setting. Used on milling machines and similar places.

Hanger, Drop—Shaft hanger to be fastened to ceiling with bearing held in lower end.

Hanger, Post—Shafting hanger for fastening to posts or other vertical structures.



Hardie—Blacksmith's cutting chisel which fits a hole in the anvil and forms the lower tool in cutting off work.

Hoist, Chain—Hoist with chain passing through pulley block used for hoisting.

Honing—A process of finishing surfaces with blocks or sticks of fine abrasives, using two or more motions. Used largely in cylinders and to some extent on piston rods and similar work.

Hubbing—The forcing of a hardened die or "hub" into cold, soft steel to produce a die or mold. A depth of ½ in. is common. Pressure averages 100 tons to the sq. in. of area.

Hunting Tooth—An extra tooth in a wheel to give it one more tooth than its mate in order to prevent the same teeth from meshing together all the time. Seldom used now.

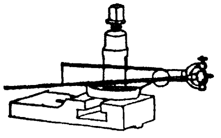
I

Indexing, Compound—Indexing by combination of two settings of index, by either adding or subtracting.

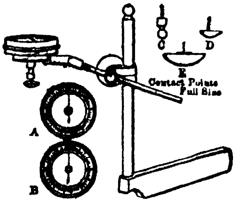
Indexing, Differential—Indexing with the index plate geared to the spindle, thus giving a differential motion that allows the indexing to be done with one circle of holes and with the index crank turned in the same direction, as in plain indexing.

Indexing, Direct—Indexing work by direct use of dividing head of milling machine.

Indicator, Lathe Test—Instrument with multiplying levers which shows slight variations in the truth of revolving work. Used for setting work in lathe or on face plate.



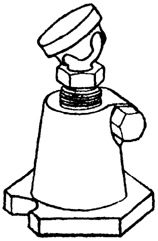
Plain Indicator



Dial Indicator

Inspection Bench—A bench with a level top, frequently of cast iron, on which finished work can be inspected with surface gages and similar instruments.

J



Jack, Hydraulic—Device for raising weight or exerting pressure by pumping oil or other liquid under a piston or ram.

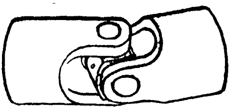
Jack, Leveling—Small jacks (usually screw jacks) for leveling and holding work on planer beds and similar places. Practically adjustable blocking.

Jack, Screw—Device for elevating weights by means of a screw.

Jam Plates—Old name for screw plates and in many cases a true one as the thread was jammed instead of cut.

Jig Bushing—Hardened steel guides for drills or other tools set into fixtures or jigs. They are now standardized.

Jig, Drill—A device for holding work while drilling, having bushings through which the drill is guided so that the holes are correctly located in the piece. Milling and planing jigs (commonly called fixtures) hold work while it is machined in the milling machine and planer. Some confine the term jig to work holders that are not fastened to the machine table. Others only to drilling operations, whether fastened or not.



Joint, Universal—Shaft connection which allows freedom in any direction and still conveys a positive motion. Most of them can transmit power through any angle up to 45 degrees.

Journal Box—The part of a bearing in which the shaft revolves.

K

Kerf—The slot or passageway cut by a saw.

Key—The piece used to fasten any hollow object to a shaft or rod. Usually applied to fastening pulleys and flywheels to shafts; or locomotive driving wheels to their axles. Keys may be square, rectangular, round or other shape and fasten in any way. Are usually rectangular and run lengthwise of shaft.

Key, Center—A flat piece of steel, with tapered sides, for removing taper-shank drills from drill spindle or similar work.

Keyway—A groove, usually square or rectangular, in which the key is driven or in which a "feather" slides. The groove in both the shaft and the piece which is to be fastened to it, or guided on it, is called a keyway.

Knurling—The rolling of depressions of various kinds into metal by the use of revolving hardened steel wheels pressed against the work. The design on the knurl will be reproduced on the work. Generally used to give a roughened holding surface for turning a nut or screw by hand.

L

Land—Metal left between flutes or grooves in drills, taps, reamers, or other tools. Some consider "land" as only the portion directly behind the cutting edge.

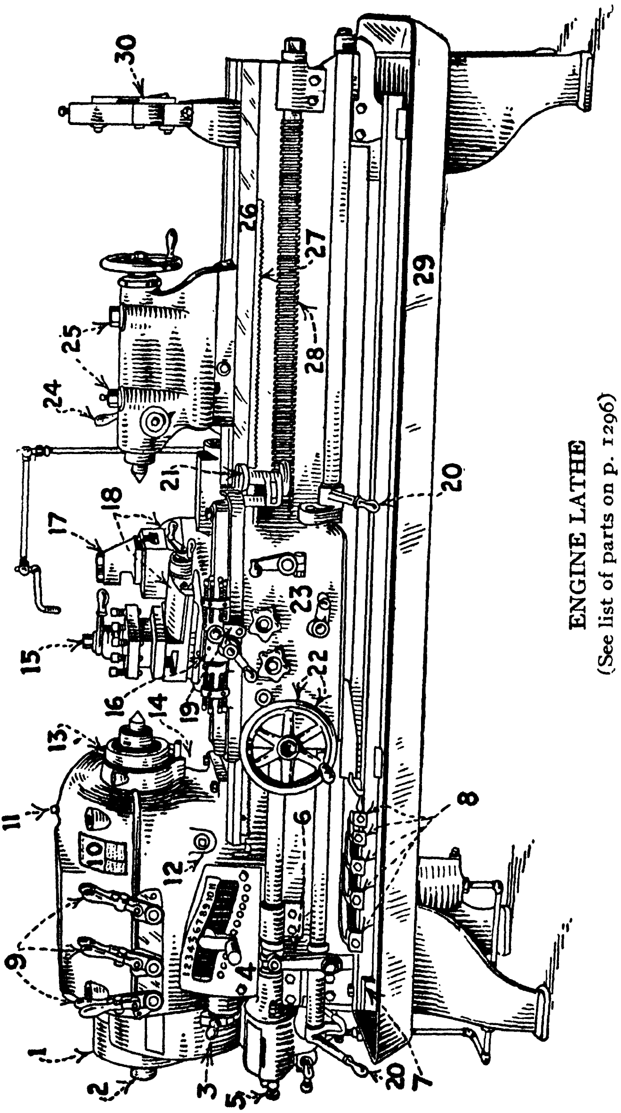
Lap—Applied to seams which lap each other. To the distance a valve must move before opening its port when valve is central on seat. To a tool usually consisting of lead, iron, or copper charged with abrasive for fine grinding. See Lap, Lead.

Lap, Lead—Usually a bar of lead or copper, a trifle smaller than the hole to be ground. Emery or some fine abrasive is used which gives a fine surface. Laps are sometimes held in the hand or are run in a machine and the work held stationary. Also consists at times of a lead-covered disk, revolving horizontally, which is used for grinding flat surfaces. Very similar in action to a potter's wheel. Flat laps are usually of cast iron.

Lapping—A refined process of finishing surfaces with a fine abrasive, such as diamond dust or very fine commercial compounds.

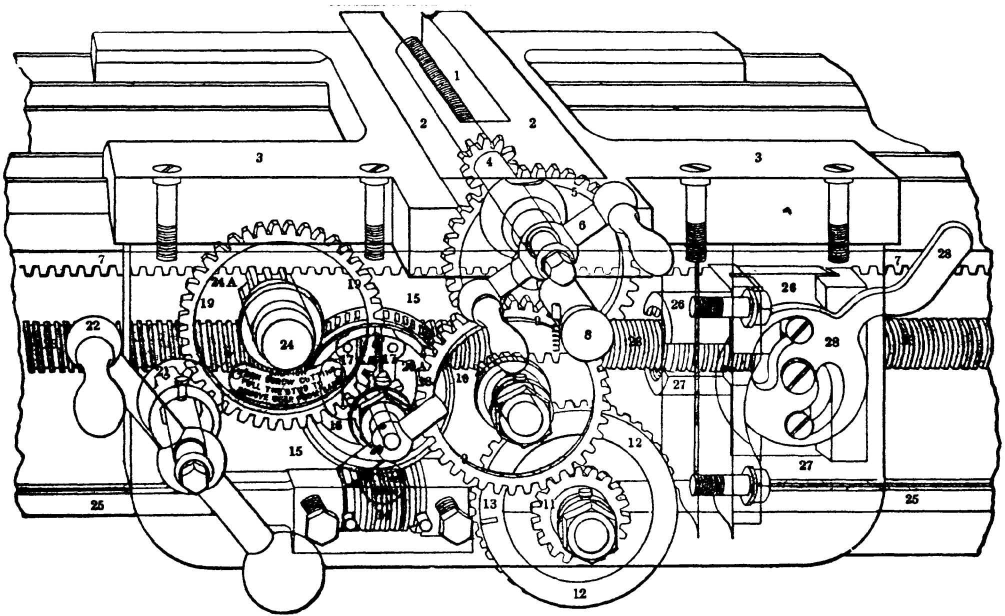
LATHE:

Lathe, Engine—The ordinary form of lathe with lead screw, power feed, etc.



ENGINE LATHE

(See list of parts on p. 1296)



LATHE APRON
(See list of parts on p. 1296)

Engine Lathe Parts

1. Ball bearing driving pulley.
2. Pulley for pump.
3. Reverse plate lever.
4. Quick change gears.
5. Head screw slip gear plunger.
6. Length feed clutch.
7. Positive feed stop.
8. Adjustable feed stops.
9. Speed change levers.
10. Speed index plate.
11. Oil hole.
12. Oil drain.
13. Double nose on spindle.
14. Oil gage.
15. Four-way tool block.
16. Base to compound nest.
17. Auxiliary tool block.
18. Compound rest.
19. Diameter stops.
20. Operating levers.
21. Thread indicator.
22. Hand feed wheel.
23. Apron.
24. Tailstock spindle clamp.
25. Tailstock clamping bolts.
26. Shears or ways.
27. Rack.
28. Lead screw.
29. Chip pan.
30. Steady rest.

Lathe Apron—Parts of

1. Cross-feed screw.
2. Cross-slides.
3. Wing of saddle.
4. Cross-feed pinion.
5. Cross-feed gear.
6. Cross-feed handle.
7. Rack.
8. Power cross-feed and control.
9. Gear in train.
10. Pinion for cross-feed.
11. Main driving pinion.
12. Bevel gear.
13. Bevel pinion.
14. Feed worm.
15. Feed-worm wheel.
16. Clutch ring.
17. Clutch levers.
18. Pinion.
19. Gear in train.
20. Feed-clutch handle.

20*A*. Clutch spreader.

21. Hand pinion.
22. Carriage handle.
23. Lead screw.
24. Rack-pinion knob.

24*A*. Rack pinion.

25. Feed rod.
26. Upper-half nut.
27. Lower-half nut.
28. Half-nut cam.

NOTE.—Cross-feed is from bevel pinion 13, through gears 12, 11, 9, 10, and 4. Regular feed is through worm 14, worm wheel 15, clutch 16, pinion 18, gears 19 and 24*A*. Hand movement is through handle 22, pinion 21, gear 19, and pinion 24*A*.

Lathe, Extension—So made that bed can be lengthened or shortened. When bed is made longer, there is a gap near head, increasing the swing for faceplate work.

Lathe, Fox—Brass workers' lathe having a "fox" or chasing bar for cutting threads. The bar has a "leader" that acts as a nut on a short lead screw or "hob" of the desired pitch (or half the pitch if the hob is geared down 2 to 1) and carries a tool along at the right feed for the thread. Sometimes has a turret on the back head.

Lathe, Gap—Has U-shaped gap in front of head stock to increase swing for faceplate work.

Lathe, Gun—For boring and turning cannons and rapid-fire guns.

Lathe, Ingot—For boring, turning, and cutting off steel ingots.

Lathe, Precision—Bench lathe made especially for small and very accurate die, jig, or model work.

Lathe, Projectile—Simply a heavy lathe for turning up projectiles. Sometimes has attachment for pointing them.

Lathe, Pulley—Especially designed for turning pulleys, can turn them crowning or straight.

Lathe, Roll Turning—For turning rolling mill, steel mill, and calendar rolls.

Lathe, Screw Cutting—Having lead screw and change gears for cutting threads.

Lathe, Shafting—For turning long shafts or similar work.

Lathe, Speed—A simple lathe with no mechanically actuated carriage or attachments.

Lathe, Spinning—For forming sheet metal into various hollow shapes, all circular. Done by forcing the sheet against a form of some kind (with a single, round-ended tool) while it is revolving.

Lathe, Turret—A lathe having a multiple toolholder, or turret, that revolves and takes the place of tail or foot stock. Many have automatic devices for turning turret and for feeding tools into the work.

Lathe, Vertical—Name given a type of vertical boring mill on account of a sidehead which acts very much like a lathe carriage and does a large variety of work that would ordinarily be done on the faceplate of a lathe.

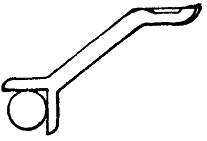
Lathe, Watchmakers'—A very small precision lathe.

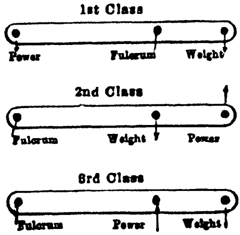
Lathe Apron—The front of a lathe carriage that supports the mechanism for feeding it along the bed. See page 1295.

Laying-Out Bench—A metal bench or plate having a level metal top, on which work can be laid out for future machining operations. Both this and the inspection bench are sometimes called "leveling benches."

Lead—The advance made by one turn of a screw.

Level, Quartering—A tool for testing driving wheels to see if crankpins are set 90 degrees apart. The level has a forked end and with the angles shown. Placing this on the crankpin and lining the edge with the center of axle should bring the bubble of level in the center. If the same result is obtained on the other wheel, the crankpins are 90 degrees apart.



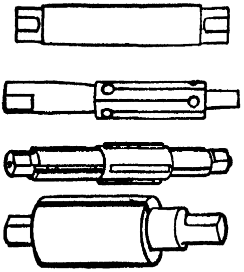


Levers—Arms pivoted or bearing on points called fulcrums. Divided into three classes as shown: First has fulcrum or bearing point between power and weight; second has weight between power and fulcrum; and third has power between weight and fulcrum.

Liner—A piece for separating pieces a desired distance; also called shim.

M

Machine Tool—The name given to any machine of that class which, taken as a group, can reproduce themselves, such as the lathe, drilling machine, planer, milling machine, etc. No other class of machines can be used to build other machines, and because of this, machine tools are known as the "master tools of industry."



Mandrel—Shafts or bars for holding *work* to be machined. Plain mandrels, as shown at the top, have a taper of about 0.010 inch per foot and are forced into the work. There are also several types of expanding mandrels, three being shown. The second and fourth mandrels have spring sleeves on a taper bar. The third has blades sliding in tapered grooves. Mandrels should not be confused with arbors that are for holding and driving cutting tools only.

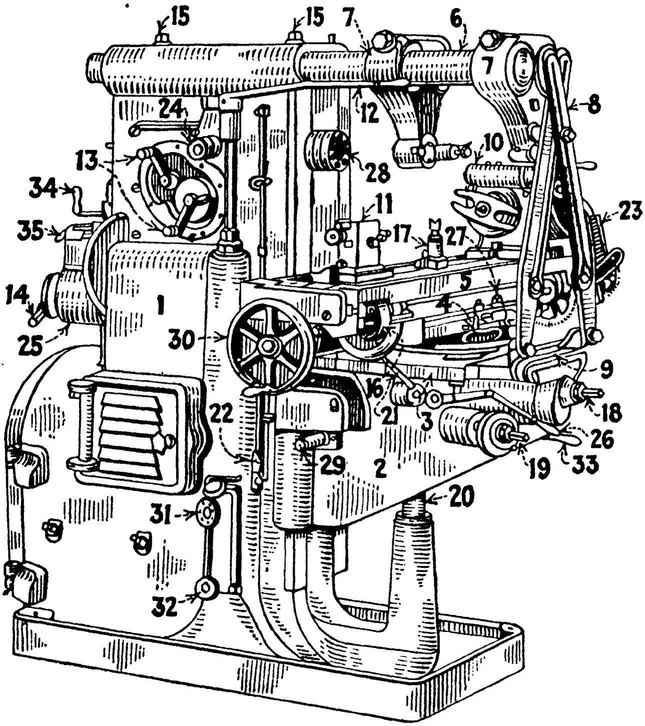
Marking Machine—A machine for stamping trade-marks, patent dates, etc., on cutlery, gun barrels, etc. Stamps are usually on rolls and rolled into work.

Master Plate—See Plate, Master.

Measuring Machine—Practically a large bench micrometer caliper of any desired form to measure work such as taps, reamers, gages, etc. Some are now made to utilize light waves instead of mechanical methods.

Milling Machine—A machine in which the operating tool is a revolving cutter. Has table for carrying work and moving it so as to feed against cutter.

Milling Machine, Universal—Has work table and feeds so arranged that all classes of plane, circular, helical, index, or other milling may be done. Equipped with index centers, chuck, etc.

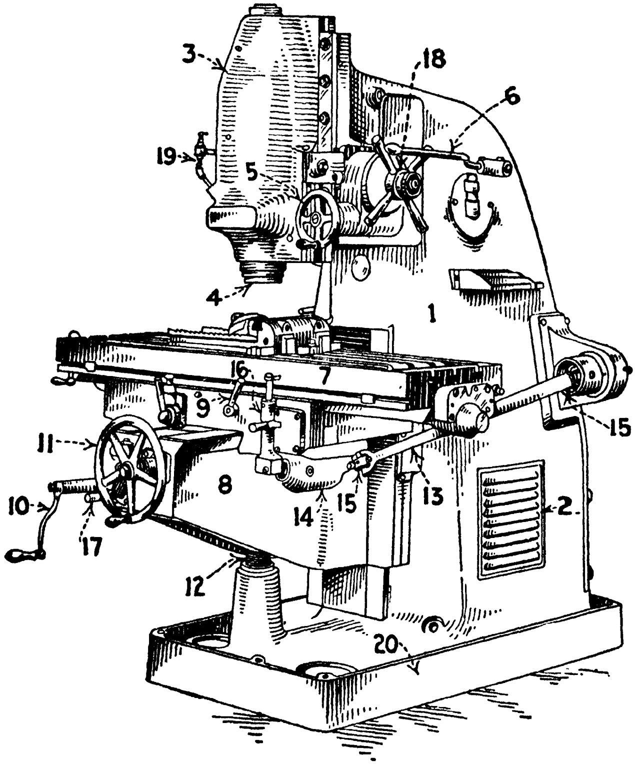


MILLING MACHINE, UNIVERSAL

1. Column.
2. Knee.
3. Saddle.
4. Universal swivel block.
5. Work table.
6. Over arm.
7. Arm bracket or arbor supports.
8. Arm braces or harness.
9. Knee clamp for braces.
10. Spiral dividing head.
11. Tailstock.
12. Starting lever.
13. Speed change lever.
14. Feed change lever.
15. Arm clamp screws.
16. Table stops.
17. Steady rest.
18. Cross feed screw.
19. Elevating shaft.
20. Elevating screw—telescopic.
21. Saddle clamp levers.
22. Vertical feed trip blocks.
23. Change gear bracket.
24. Spindle lock.
25. Feed box.
26. Cross and vertical feed handle.
27. Table trip handle.
28. Spindle collar.
29. Interlocking feed lever.
30. Table screw.
31. Oil sight gage.
32. Oil drain plug.
33. Cross and vertical feed reverse lever.
34. Primary feed selection lever.
35. Secondary feed selection lever.

Milling Machine, Vertical—Differs from horizontal machine mainly in having a vertical spindle for carrying the cutter.

Miter—A bevel of 45 degrees.



MILLING MACHINE, VERTICAL

1. Column.
2. Ventilators for motor in base.
3. Spindle head.
4. Spindle nose.
5. Worm gear head control.
6. Control lever.
7. Table.
8. Knee.
9. Saddle.
10. Hand elevation of knee.
11. Saddle feed wheel.
12. Knee elevating screw.
13. Power feed drive.
14. Feed gear box.
15. Universal joints.
16. Table control.
17. Power saddle control.
18. Direct head control.
19. Spindle oiler.
20. Base.

N

Necking Tool—Tool for turning a groove or neck in a piece of work.

Nose—In shop work the term is applied to the business end of tools or things. The threaded end of a lathe or milling-machine spindle or the end of "hog-nose drill" or similar tool.

Nut, Castle or Castellated—A nut with slots across the outer end to receive a cotter pin put through the bolt to prevent loosening.

Nut, Cold Punched—A nut punched from flat bar stock. The hole is usually reamed to size before tapping.

Nut, Hot Pressed—A nut formed hot in a forging machine.

Nut Machine—A machine for cutting, drilling, and tapping nuts from a bar or rod.

Nut Tapper—A machine for tapping hole in nuts.

Nuts—See Bolts; also Section XV.

O

Ogee—Name given to a finish or beading consisting of a reverse curve. Applied to work of any class, wood or iron.

Oval—Continuously curved but not round, as a circle which has been more or less flattened.

Overhead—A term usually applied to expenses that come from rent, taxes, interest on investment, depreciation, upkeep or maintenance, supervision, insurance and any other expenses that do not come under the head of direct labor or material. Some separate it into machine overhead, etc.

P

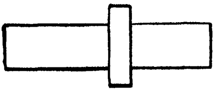
Pawl—A hinged piece which engages teeth in a gear, rack or ratchet for moving it or for arresting its motion. Sometimes used to designate a piece such as a reversing dog on a planer or milling machine.

Peening—The stretching of metal by hammering or rolling the surface. Used to compress babbitt to fit tightly in a bearing, to straighten bars by stretching the short or concave side, etc.

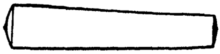
Pickling Castings—Dipping into acid solution to soften scale and remove sand. Solution of eight or ten parts of water to one of sulphuric acid is used for iron. For brass use five parts water to one of nitric acid.

Pickling Forgings—Putting in bath of one part sulphuric acid to twenty-five parts boiling water to remove scale. Can be done in 10 minutes. Rinse in boiling water and they will dry before rusting.

Pin, Collar—A collar pin is driven tight into a machine frame or member and adapted to carry a roll, gear, or other part at the outer end. It differs from the collar stud in not having a thread at the inner end. When drilled through the end for a cotter pin, it is known as a "fulcrum pin," as it is then especially suited for carrying rocker arms, etc.



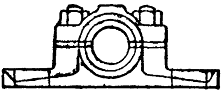
Pin, Dowel, Screw—Dowel pins are customarily made straight, or plain taper and fitted into reamed holes. When applied in such a position in a mechanism that it is impossible to remove them by driving out, they are sometimes threaded and screwed into place. They position two mating parts.



Pin, Taper—Taper pins for dowels and other purposes are regularly manufactured with a taper of $\frac{1}{4}$ inch to the foot and from $\frac{3}{4}$ to 6 inches long, the diameters of the large end of the sizes in the series ranging from about $\frac{5}{32}$ to $\frac{23}{32}$ inch. The reamers for these pins are so proportioned that each size "overlaps" the next smaller size by about $\frac{1}{2}$ inch.

Pitch—The distance from the center of one screw thread, or gear tooth or serration of any kind, to the center of the next. In screws with a single thread the pitch is the same as the lead but not otherwise.

Pitch Diameter—In a screw thread the diameter at the center of the thread depth, without considering clearance. In gears, the diameter at the point of contact of the teeth. This may be at the center of the tooth (without clearance) or may be moved in or out, according to the design of the tooth.

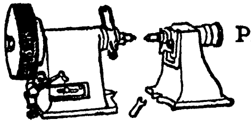


Pillow Blocks—Low shaft bearings, resting on foundations, or floors, or other supports.

Pitman—A connecting rod; term used more commonly in connection with agricultural implements.

Planchet—Blank piece of metal punched out of a sheet before being finished by further work. Such as the blanks from which coins are made.

Planer—A machine for producing plane surfaces on metals. The work is held on table or platen which runs back and forth under the tool which is stationary.



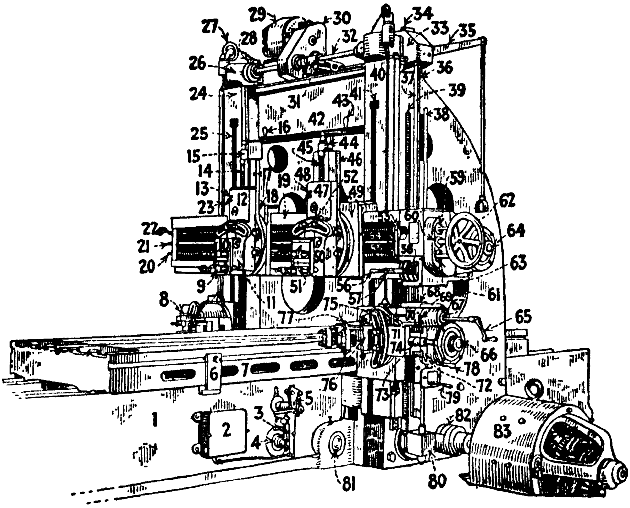
Planer Centers—A pair of index centers to hold work for planing. Similar to plain milling machine centers.

Planer, Open Side—A planer with only one upright or housing, supporting an overhanging arm which takes the place of the usual crossrail. Useful in planing work too wide to go between the housings of the ordinary planer.

Planer, Radius—For planing parts of circles, such as links for locomotive or stationary-engine valve motion.

Planer, Rotary—Really a large milling machine in which the work is carried past a rotary cutter by the platen or table.

Planer, Traveling Head—Planer in which work is stationary and tool moves over it. Seldom used in United States.



PLANER

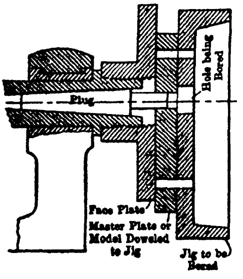
List of Parts of Planer

1. Bed.
2. Master switch.
3. Slotted lever.
4. Bull gear shaft.
5. Shifter lever.
6. Front dog, right hand.
7. Table,
8. Left-hand sidehead.
9. Tool clamp.
10. Apron of left-hand rail head.
11. Toolbox of left-hand rail head.
12. Slide of left-hand head.
13. Slide clamp of left-hand head.
14. Downfeed screw, left-hand head.
15. Graduated collar for downfeed.
16. Downfeed crank.
17. Harp, left-hand head.
18. Saddle of left-hand head.
19. Rail.
20. Cross-feed screw for right-hand head.
21. Downfeed rod.
22. Cross-feed screw for left-hand head.
23. Counterweight cable for left-hand sidehead.
24. Left-hand housing.
25. Left-hand rail elevating screw.
26. Rapid-traverse gear case, left hand.
27. Sidehead counterweight sheave.
28. Centralized oiler for traverse gears.
29. Traverse motor.
30. Rail-setter gear case.
31. Safety clutch for rail setter.
32. Elevating shaft.
33. Case for traverse gears, right hand.
34. Centralized oiler for traverse gears.
35. Rail-setter lever.
36. Traverse-control shaft.
37. Traverse-drive shaft.
38. Feed-drive shaft.
39. Sidehead screw, right hand.
40. Right-hand housing.
41. Right-hand rail elevating screw.
42. Top brace.
43. Downfeed crank for right-hand head.
44. Graduated collar for downfeed, right-hand head.
45. Downfeed screw, right-hand head.
46. Harp for right-hand head.
47. Slide for right-hand head.
48. Slide-clamping screw for right-hand head.
49. Saddle for right-hand head.
50. Toolbox for right-hand head.
51. Apron for right-hand head.
52. Toolbox clamping bolts, right-hand head.
53. Graduated collar for cross-feed screw of left-hand head.

54. Graduated collar for downfeed at end of rail.
55. Graduated collar for cross-feed of right-hand head.
56. Traverse lever for left-hand head across rail.
57. Traverse lever for slides up or down.
58. Traverse lever for right-hand head across rail.
59. Ratchet feed gear for left-hand head.
60. Ratchet feed gear for downfeed.
61. Ratchet feed gear for right-hand head.
62. Rail-lock shaft.
63. Feed reverse-tumbler gear.
64. Cantslip feed dial.
65. Sidehead crank.
66. Sidehead cantslip feed dial.
67. Ratchet feed gear for sidehead.
68. Centralized oiler for sidehead.
69. Clamp for saddle of right-hand sidehead.
70. Saddle of right-hand sidehead.
71. Clamp for sidehead slide.
72. Harp for sidehead.
73. Graduated collar for feed, sidehead.
74. Slide for sidehead.
75. Sidehead toolbox.
76. Sidehead apron.
77. Self-releasing plunger for sidehead apron.
78. Crank for in-and-out feed on sidehead.
79. Rapid traverse lever for sidehead.
80. Bevel gears for feed drive.
81. Shaft for second intermediate gear.
82. Flexible coupling for drive shaft.
83. Reversing motor.

Planishing—The finishing of sheet metal by hammering with smooth-faced hammers or their equivalents.

Plate, Master—A steel plate serving as a model by which holes in jigs, fixtures, and other tools are accurately located for boring. In the illustration the piece to be bored is shown doweled to the master plate, which is mounted on the faceplate of the lathe. In the master plate there are as many holes as are to be bored in the work, and the center distances are correct. The plate is located on a center plug fitting the lathe spindle, and after a given hole is bored in the work, the master plate and work are shifted and relocated with the center plug in the next hole in the plate and the corresponding hole in the work is then bored out. This is one of the most accurate methods employed by the toolmaker on precision work. Largely used before the advent of the jig borer.



Platen—A work-holding table on miller, planer, or drill.

Plumb, Bob, Mercury—Plumb bob filled with mercury to secure weight in a small space.

PRESSES:

Press, Blanking—For heavy punching or swaging.

Press, Broaching—A press for pulling or forcing broaches through holes in metal work.

Press, Cabbaging—For compressing loose sheet-metal scrap into convenient form for handling and remelting.

Press, Coining—For making coins from metal planchets previously blanked out. Usually has a toggle action.

Press, Double Action—Has a telescoping ram or one ram inside the other, each driven by an independent cam so that one motion follows the other and performs two operations for each revolution of the press.

Press, Forcing—For forcing one piece into another, such as a rod of brass into a locomotive connecting rod.

Press, Forging—For forging metal by subjecting it to heavy pressure between formers or dies.

Press, Horning—For closing side seams on pieced tinware.

Press, Inclinable—One that can be used in vertical or inclined position.

Press, Pendulum—Foot press having a pendulum-like lever for applying power to the ram.

Press, Screw—Pressure is applied by screw.

Press, Straight-sided—Made with perfectly straight sides so as to give great strength and rigidity for heavy work.

Profiling Machine—A milling machine in which the cutter can be made to follow outline or pattern in shaping small parts of machines. Practically a vertical milling machine.

Protractor, Bevel—Graduated semicircular protractor having a pivoted arm for measuring off angles.

Pull-pin—A means of locking or unlocking two parts of machinery. Sometimes slides gears in or out of mesh and at other times operates a sliding key which engages any desired gear of a number on stud.

Pulley, Gallow or Guide—Loose pulley mounted in movable frames to guide and tighten belts.

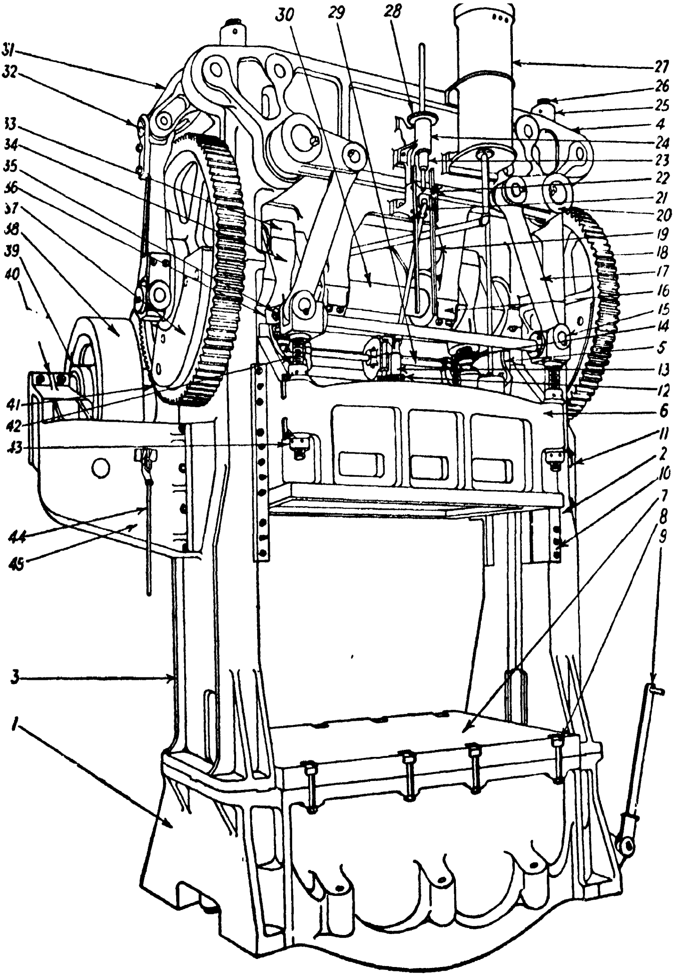
Pulley, Idler—A pulley running loose on a shaft and driving on machinery, merely guiding the belt. Practically same as a "loose pulley."

Pulley, Loose—Pulley running loosely on shaft doing no work. Carries belt when not driving tight (or fast, or working) pulley. Is used on countershafts, for belt driven machines idle part of time. Belt is then on the loose pulley, but when shifted to tight pulley, the machine starts up.

Punching—A piece cut out of sheet stock by punch and die; the same as blank.

Punch, Belt—Hollow, round, or elliptical punch for cutting holes for belt lacing.

Punch Press—Machine in which a ram moves a punch against, or through, a die held in the frame on a bed or bolster. Made for punching holes or forming metal. Some now form a whole automobile top at one stroke.



LARGE PUNCH PRESS

PUNCH PRESS

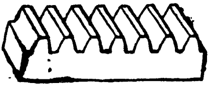
1. Bed.
2. Right-hand upright.
3. Left-hand upright.
4. Crown (these four parts together with the necessary tie-rod nuts (part 25) and the tie rods (part 26) constitute the frame which may also be of a solid casting on some of the smaller machines).
5. Plunger or inner slide. (On single-action presses this would be called a slide.)
6. Blank-holder or outer slide.
7. Bolster.
8. Bolster bolts.
9. Operating lever.
10. Gib.
11. Intermediate gear-supporting bracket.
12. Intermediate adjusting gear.
13. Worm-gear case.
14. Bevel gear.
15. Yoke.
16. Center bearing cap.
17. Main toggle link.
18. Right-hand main gear.
19. Cross-head guide.
20. Main toggle lever.
21. Universal joint.
22. Cross head.
23. Sleeve.
24. Cross-head guide bracket.
25. Tie-rod nut.
26. Tie rod.
27. Air cylinder.
28. Bevel gear.
29. Adjusting shaft.
30. Crankshaft.
31. Universal lever.
32. Universal connection leaf.
33. Connection cap.
34. Connection.
35. Connection screw-clamp adjusting screw.
36. Connection screw clamp.
37. Counterweight.
38. Flywheel.
39. Flywheel clutch.
40. Side-arm bracket spacer.
41. Left-hand main gear.
42. Blank-holder adjusting screw.
43. Blank-holder adjusting screw nuts.
44. Flywheel brake.
45. Side-arm bracket.

Quadrant—A segment of a circle. The swinging plate carrying the change gears in the feed train at the end of the lathe.

Quick Return—A mechanism employed in various machines to give a table, ram, or other member a rapid movement during the return or noncutting stroke.

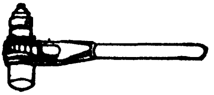
Quill—A hollow shaft that revolves on a solid shaft, carrying pulleys or clutches. When clutches are closed, the quill and shaft revolve together.

R



Rack—A strip cut with teeth so that a gear can mesh with it to convert rotary into reciprocating motion or *vice versa.*

Ratchet—A gear with triangular-shaped teeth adapted to be engaged by a pawl which either imparts intermittent motion to the ratchet or else locks it against backward movement when operated otherwise.



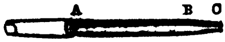
Ratchet Drill—Device for turning a drill when the handle cannot make a complete revolution. A pawl on the handle drops into a ratchet wheel on the barrel so that it can be turned one or more teeth.

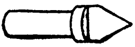
REAMERS:

Reamer—A tool to enlarge a hole already existing, whether a cast or cored hole or one made by a drill or boring bar. Reamers are of many kinds and shape as indicated below. Usually a reamer gives the finishing touch to a hole.

Ball Reamer—Usually a fluted, hemispherical reamer for making the receiving portion of a ball joint. It is considered advisable to space the teeth irregularly, as this tends to prevent chattering.

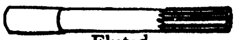
Bridge Reamer—A reamer used by boilermakers, bridgebuilders, shipbuilders, etc., has a straight body from *A* to *B* and tapered end from *B* to *C*. This reamer has a taper shank and can be used in an air drill.



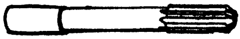


Flat

Center Reamer—Center reamers, or countersinks for centering the ends of shafts, etc., are usually made 60 degrees included angle. Combined center drill and reamer are now universally used.



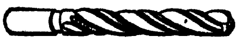
Fluted



Rose

Chucking Reamer—Chucking reamers are used in turret machines. The plain, fluted type has teeth relieved the whole length; while the rose reamer cuts only on the end, as there is no peripheral clearance. Where possible, reamers used in the turret should be mounted in floating holders which allow the reamer to play sidewise sufficiently to line up with the hole in the work which may be so drilled or bored as not to run perfectly true prior to the reaming operation.

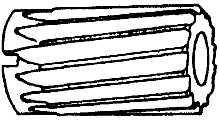
Chucking Reamer (Three-Groove)—Spiral-fluted chucking reamers with three and four grooves are employed for enlarging cored holes, etc. They are also made with oil passages through them and in this form are adapted to operating in steel.



Flat Reamer—A reamer made of a flat piece of steel. Seldom used except on brass work and then usually packed with wooden strips to fit the hole tightly. Flat reamers are not much used except for taper work.

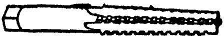
Half-Round Reamer—Used considerably in some classes of work, particularly in small sizes and taper work when taper is slight. Not much used in large sizes. Somewhat resembles the "hog-nose drill" in general appearance except that this is always quite sharp on cutting edge.

Rose Reamer—A reamer with teeth only on the front end and only clearance or chip grooves, or flutes in the body. Cutting edge is usually 45 degrees.

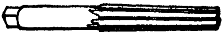


Shell Reamer—Shell reamers have taper holes to fit the end of an arbor on which they are held in the chucking machine. They are made with both straight and helical flutes. Made with a variety of flutes. Taper hole is $\frac{1}{8}$ inch to the foot.

Taper Reamer—For finishing taper holes two or more reamers are sometimes used. The roughing reamer is often provided with nicked or stepped teeth to break up the chip. Taper reamers are also made with helical teeth. Where the taper is slight, the helix should be left-hand to prevent the reamer from drawing in too fast; where the taper is abrupt, the teeth, if cut with right-hand helix, will help hold the reamer to the cut and make the operation more satisfactory.



Roughing



Finishing

Taper-Pin Reamer—See Taper Pins.

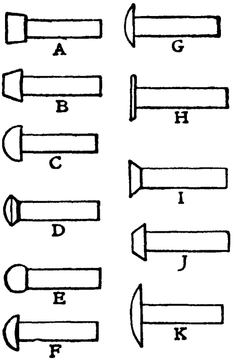
Recess—A groove below the normal surface of work. On flat work a groove to allow tool to run into as a planer, or a slide to run over as a crosshead on a guide. In boring a groove inside a hole. If long it is often called a "chamber."

Relief or Relieving—The removing of material or the amount removed to reduce friction back of cutting edge of a drill, reamer, tap, etc. Also applied to other than cutting tools. See Backing Off.

Riffle—Name given a small file used by die sinkers and on similar work.

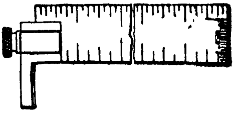
Rivet—A pin for holding two or more plates or pieces together. A head is formed on one end when made; the other end is upset after the rivet is put in place and draws the riveted members close together.

Rivet Machine—Machine for making rivets from metal rods.



Rivets

A—Machine head
B—Cone head
C—Wheel head
D—Oval countersunk head
E—Globe head
F—Round head
G—Truss head
H—Flat head
I—Countersunk head
J—Bevel head
K—Wagon-box head.



Rule, Hook—Rule with a hook on the end for measuring through pulley holes and in similar places.

Rule, Keyseat—For laying out keyseats on shaft or in hubs.

Rule, Shrink—Graduated to allow for shrinkage in casting. Used by pattern makers and varies with metal to be cast.

Rust Joint—A joint made by application of cast-iron turnings mixed with sal ammoniac and sulphur to cause the turnings to rust and become a solid body.

S

Sand Blast—Sand is blown by compressed air through a hose as desired. Used to clean castings, stonework, etc.

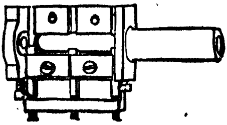
Saw, Band—Continuous metal band, toothed on one edge and guided between rolls. Mostly used on woodwork, but its use on metal work is increasing.

Saw, Cold—Machines for sawing metal with circular saws.

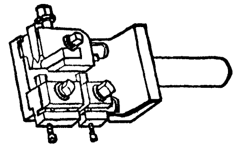
Saw—See Hacksaw.

Scarf—The bevel edge formed on a piece of metal which is to be lap-welded.

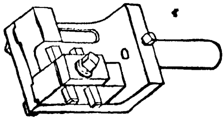
SCREW-MACHINE TOOLS:



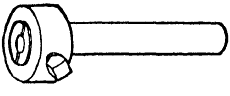
Box Tool, Bushing—The cutters in this tool are placed with edges radial to the stock and may be adjusted to turn the required diameter by the screws in the rear. The stock is supported in a bushing and must therefore be very true and accurate as to size.



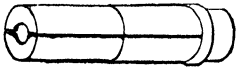
Box Tool, Finishing—The material turned in this box tool is supported by adjustable back-rest jaws, and the cutters are also adjustable in and out, as well as lengthwise, of the tool body.



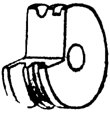
Box Tool, Roughing—This tool has one or more cutters inverted over the work and with cutting edges tangent to the material. The back rest is bored out the size the screw or other piece is to be turned, and the cutter turns the end of the piece to size before it enters the back rest. Sometimes a pointing tool is inserted in the shank for finishing the end of the work.



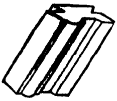
Drill Holder—The end of the drill holder is split and provided with a clamp collar by which the holder is closed on the drill.



Feed Tube—The screw-machine feed tube or feed finger is closed prior to hardening and maintains at all times a grip on the stock. The rear end is threaded and screwed into the tube by which it is operated. It is drawn back over the stock and when the chuck opens, is moved forward, feeding the stock the right distance for the next piece.

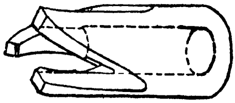


Circular

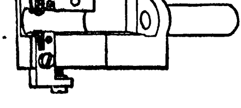


Dovetail

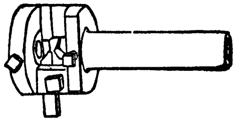
Forming Tools—Circular forming cutters are generally cut below center to give proper clearance, and the tool post is bored a corresponding amount above center to bring the tool on the center line. Dovetail cutters are made at an angle of about 10 degrees for clearance.



Hollow Mill—Usually made with three prongs or cutting edges and with a slight taper inside toward the rear. A clamp collar is used on mill like a spring-die collar, and a reasonable amount of adjustment may be obtained by this collar. Hollow mills are frequently used in place of box tools for turning work in the screw machine.

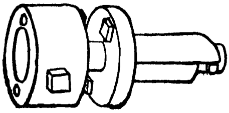


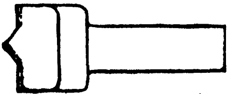
Knurling Tool—The two knurls in this box are adjustable to suit different diameters of work.



Pointing Tool—The bushing in this tool receives and supports the end of the round stock, and the cutters carried in the frame form and point the end.

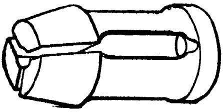
Revolving Die Holder—The common type of revolving die holder that is generally used with spring dies has a pair of driving pins behind the head and in the flange of the sleeve which fits into the turret hole. At the rear end of the sleeve is a cam surface that engages a pin in the shank of the head when the die is reversed. The die is run on to the work with the driving pins engaged. When the work is reversed, the cam at the rear engages the pin in the shank and holds the die from turning so that it must draw off the work.

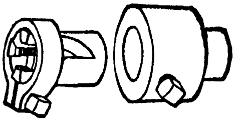




Spotting Tool—This tool spots a center in the end of the bar of stock to allow the drill to start properly, and also faces the end of the piece true. Sometimes called "centering and facing" tool. It is desirable to have the included angle of the cutting point less than that of the drill which follows it, in order that the latter may start true by cutting at the corners first.

Spring Collet—Spring collets or chucks are made to receive round, square, hexagonal, or other stock worked in the screw machine. The collet is hardened and is closed in operation by being pressed into the conical cap into which it fits. When released, it springs open sufficiently to free the stock and allow it to be fed through the collet.

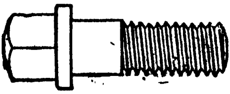




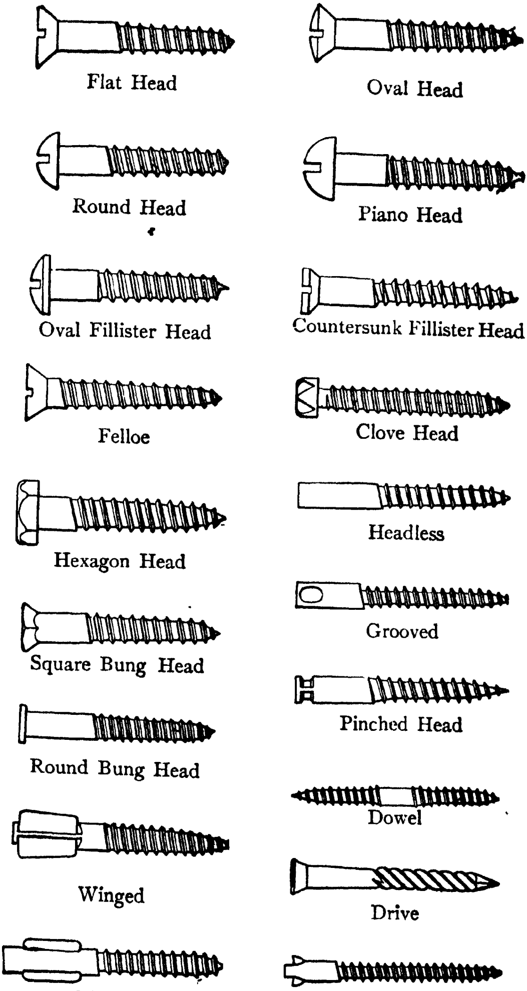
Spring Die and Extension—Spring dies or prong dies are provided with a collar at the end for adjusting and are easily sharpened by grinding in the flutes.

Screw Plates—Holders for dies for cutting threads on bolts or screws. Dies are usually separate but sometimes cut in the piece that forms the holder.

Screws—The machine screws in most common use are shown under Bolts, Nuts, and Screws. A few of the less used varieties are shown here. See Section XV.



Collar Screw—Collar or collar-head screws are used for much the same purposes as regular capscrews and, in fact, are sometimes designated as "collar" capscrews or "collar-head" capscrews.



Flat Head

Oval Head

Round Head

Piano Head

Oval Fillister Head

Countersunk Fillister Head

Felloe

Clove Head

Hexagon Head

Headless

Square Bung Head

Grooved

Round Bung Head

Pinched Head

Dowel

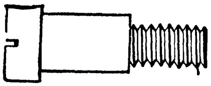
Winged

Drive

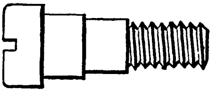
Winged

Winged Head

WOOD SCREWS

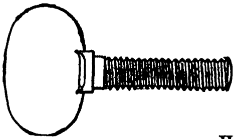


Single Shoulder

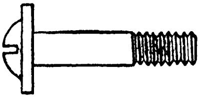


Double Shoulder

Shoulder Screw—Shoulder screws are commonly used for carrying levers and other machine parts that have to operate freely. The screw body is enough longer than the thickness of the piece pivoted thereon to allow the latter to work easily when the screw is set up tight against the bottom of the shoulder. With double shoulders two members may be mounted side by side and left free to operate independently of each other.



Thumbscrew—A screw with a winged or knurled head, which may be operated by hand when a quick and light clamping effect is desired.



Washer-Head Screw—The washer formed on this screw enables it to be used for holding pieces with large holes without applying a loose washer.

Wood Screws—Wood screws are made in an endless variety of forms, a number of which are shown on the following page. They range in size from No. 0 to No. 30 by the American Screw Company's gage and are regularly made in lengths from ¼ inch to 6 inches. Generally the thread is cut about seven-tenths of the total length of the screw. The flat-head wood screw has an included angle of head of 82 degrees.

Sector—A device used on an index plate of a dividing head for indicating the number of holes to be included at each advance of the index crank in dividing circles. The sector can be opened or closed to form as large or small an arc as necessary to cover the desired number of holes for each movement of the crank.

Set—The bend to one side of the teeth of a saw. Any deformation of metal or other material stressed beyond its elastic limit.

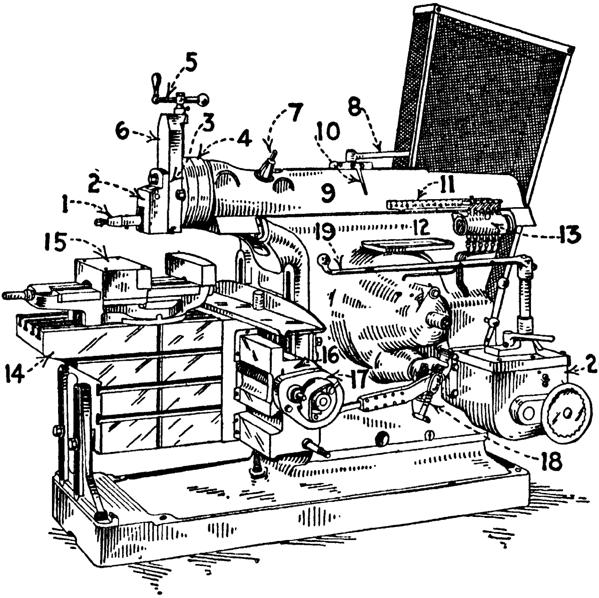
Shaft, Flexible—Shaft made of a helical spring or of jointed parts, to transmit power in varying directions. Usually confined in a casing of fabric or of flexible tubing.

Shaft, Line—The shafting driving the machinery of a shop or section of a shop by means of pulleys and belts.

Shaper—A machine in which the work is held on table or knee while the tool held by a tool post on the moving ram moves across it. Table is adjustable for depth of cut, etc.

Shaper, Crank—A shaper in which the ram is driven by a crank motion.

Shaper, Draw Cut—The cutting stroke takes place when tool is moving toward frame of machine. This tends to draw the parts together.



SHAPER

1. Tool post.
2. Clapper block.
3. Clapper box.
4. Tool head.
5. Tool-head feed screw.
6. Tool slide.
7. Ram adjuster.
8. Position lever.
9. Ram.
10. Stroke indicator.
11. Stroke scale.
12. Ram guide.
13. Oiler.
14. Table.
15. Vise.
16. Saddle.
17. Cross-feed.
18. Feed adjustment.
19. Control lever.
20. Speed change box.

Shaper, Gear—A machine for planing or shaping gear teeth by using a hardened cutter, shaped like a pinion gear as a tool, and moving it across the face of the gear.

Shaper, Geared—The ram is driven by rack and pinion with a slow cutting stroke and a quick return by shifting open and crossed belts the same as on a planer.

Shapers, Traverse or Traveling Head—The ram feeds along work, which is stationary.

Shaving—The removal of small quantities of material to ensure correct size or shape. Refers to both punch and die work and to finishing of gear teeth by special cutting tools.

Shears—Tools for cutting metals between two blades. The ways on which the lathe carriage and tail stock move are called "shears" by some, "ways" by others. They may be either V, flat, or any other shape. Also a hoisting apparatus used on wharves or docks, consisting of two heavy struts like an inverted V.

Shedder—A plate or ring operated by springs or by a rubber pad to eject a blank from a compound die. It acts as an internal stripper, and is sometimes known as an "ejector."

Sherardizing—The name given to a new process of dry galvanizing of any iron product.

Shifter Forks—Arms to guide belt from tight to loose pulley, or *vice versa*, by pressing the sides.

Shim—A liner or piece to place between surfaces to secure proper adjustment.

Shrink Fit—Expanding an outer member by heat to increase its diameter so it will go over the inner member, which is slightly larger than the hole. On cooling, it contracts and grips the inner piece.

Single-Point Boring—Boring with a single pointed tool. For accurate work either cemented carbide or diamond cutting tools are used. Sometimes called "diamond boring."

Slip Washer—See Washer, Open.

Slotted Washer—See Washer, Open.

Slotter—A machine for planing vertical surfaces or cutting slots. The tool travels vertically. Some call it vertical shaper.

Socket, Grip—A device for driving drills and other tools with either a straight or taper shank.

Sow or Sow-Block—Local name for a chuck for holding work, such as dies. A ball chuck.

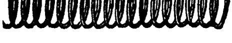
Spinning—The forming of sheet metal by rolling it against forms such as lamp bodies. Lathes are made especially for this work.

Spline—Used in some sections in place of "key" and in others the same as "feather." See Key and Feather.

Split Nut—Nut split lengthwise so as to open for quick adjustment.

Spot or Spotting—Spotting is making a spot or surface for a locating point or to lay out from. Also used to designate place turned for steady rest support, before turning balance of a shaft. Sometimes the finish given by a scraper or by an abrasive, to make a variegated surface, is called spotting.

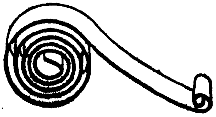
SPRINGS:



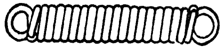
Spring, Compression—A helical spring which tends to shorten in action.

Spring, Helical—A spring coiled lengthwise of its axis like a screw thread. Often incorrectly called a spiral spring.

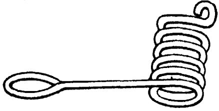
Spring, Leaf—A built-up spring made of flat stock like a carriage spring or locomotive driving spring.



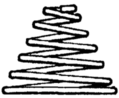
Spring, Spiral—A spring wound with one coil over the other as in a clock spring. Usually of flat stock, but not always.



Spring, Tension—A helical spring which tends to lengthen in action.



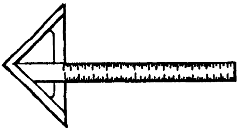
Spring, Torsion—A helical spring which operates with a coiling or uncoiling action as a door spring.



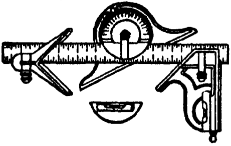
Spring, Valve—A helical spring used on valve stems and similar places, each coil being smaller than the one below, in order that the spring may close up into a very small space and then have a considerable range of action.

Sprue Cutter—A cutting punch for trimming sprues from soft metal castings.

Square, Caliper—A square with a caliper adjustment for laying out work.

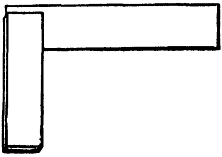


Square, Center—For finding the center of a round bar by placing across the end and scribing lines in two different positions. Also used as a T square. Not so much used as formerly.



Square, Combination—A tool combining square, level, and protractor in one tool.

T Square—A straight edge with a 90-degree head at one end commonly used on the drawing board for drawing straight lines. It also forms a guide on which triangles are used.



Square, Try—Small square for testing work as to its being at right angles.

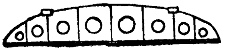
Star Wheel Feed—An intermittent feeding device where a wheel with projections on its edge is fastened to a feed screw and turns it whenever a point on the wheel strikes a pin. Frequently used on boring bars where the tool head is fed by a screw as the bar turns in the bore.

Steady Rest—A rest attached to the lathe ways for supporting long, slender work.

Steel, High-Speed—A name given to steels which do not lose their hardness by being heated under high-speed cuts. Alloy steels which depend on tungsten, chromium, manganese, molybdenum, etc., for their hardness.

Stocks, Ratchet—Die stocks with ratchet handles.

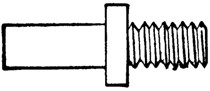
Straight Edge—A piece of metal having one edge ground and scraped flat and true. Small ones are sometimes made of steel, but large, straight edges are usually of cast iron, proportioned to resist bending, and are used for testing the truth of flat surfaces such as planer ways.



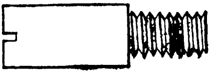
Strapping—A method of buffing by the use of a flexible strap or belt, usually made of cloth and covered with abrasive held in place by glue. Runs over two pulleys or one pulley and a rod or plate at high speed.

Stripper—A plate placed over the die in a punch press with a gap beneath to admit the sheet stock and an opening to allow the punch to pass freely; upon the upstroke of the punch it prevents the strip of metal from lifting with the punch.

Stud, Collar—The collar stud forms a satisfactory device for carrying gears, cam rolls, rocker levers, etc. It is often provided with a hole at the end for a cotter pin or is slotted for a split washer, to retain the gear, or other part in place.

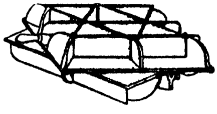


Stud, Shoulder—A stud of this form is used for mounting levers and other parts which could be operated on a plain, unthreaded stud, which stud, however, cannot be conveniently set or removed when necessary. It is also a form of post or guide sometimes employed in machine construction for carrying one or more sliding parts.



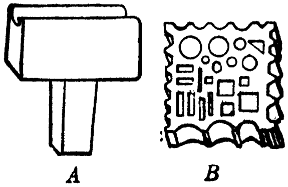
Stud, Threaded—See Bolts, Nuts, and Screws. Section XV.

Superfinish—A method of producing an extremely smooth surface by the use of fine abrasive stones moved in a number of directions over the work. Devised by D. A. Wallace, in 1938.

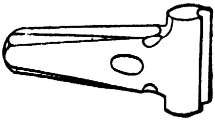


Surface Plates—Cast-iron plates with surfaces scraped flat for use in testing work. Should be made in sets of three and so scraped that each one has a perfect bearing with the two others.

Swaging—Changing the sectional shape of a piece of metal by hammering, rolling, or otherwise forcing the particles to change shape without cutting.



Swaging Blocks—Blocks of cast iron or steel to assist blacksmith in swaging and bending iron to various shapes. *A* is for use in the hardie hole in the anvil, *B* can be used anywhere but is usually on or beside the anvil.



Swaging Hammer—A connection with the swaging block to swage metal to the desired size and shape.

Swaging Machine—A machine for reducing, tapering or pointing wire or tubing either between rolling dies or by hammering with rapid blows between dies of suitable shape.

Sweating—Another name for soldering.

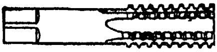
Swing of a Lathe—In the United States the swing of a lathe means the largest diameter of the work that can be swung over the ways or shears. In England it means the distance from lathe center to the ways or one-half the United States measurements.

T

Take-up—Name given to device for taking up slack in belt or rope drives.

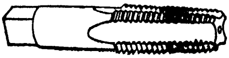
Tap—Hardened and tempered steel tool for cutting internal threads. Has a thread cut on it and flutes to give cutting edges.

Tap, Echols Thread—This form of tap has every other thread cut away on each land, but these are staggered so that a space on one land has a tooth behind it on the next land. This is done for chip clearance.

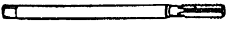


Tap, Hob, Sellers—Has threads in center and numerous flutes. For hobbing dies and chasers.

Tap, Patch-Bolt—Tap for boilermakers' use in patching boilers. Sizes vary by sixteenths from ½ to 1¼ inches. All threads are 12 to the inch, and taper is ¾ inch per foot.

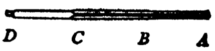


Tap, Pulley—Tap with a long shank to reach the hub of pulley for tapping setscrew holes.



Tap Remover—Device for removing broken taps. Usually has prongs which go down in the flutes and around the central portion.

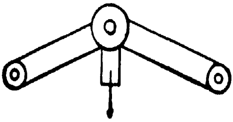
Tap, Staybolt—Tap for threading boiler sheets for staybolts. *A* reams the hole, *B* is a taper thread, *C* is straight thread of right size, *D* square for driving tap. All standard staybolt taps have 12 threads per inch.



Tap, Step—Tap made with "steps" of varying diameters. Front end cuts part of thread, next step takes out more and so on to the end. Only used for heavy threads, usually square or Acme.

Tapped Faceplate—Having a number of tapped holes instead of slots. Studs screw in at any desired point.

Tapping Machine—For cutting threads with taps (tapping) in nuts or other holes.



Toggle—Arrangement of levers to multiply pressure obtained by making movement given to work very much less than movement of applied power.

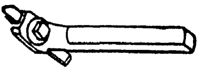
Tolerance—Permissible variation from basic dimension.

Tolerance, Bilateral—Permissible variation both above and below basic. A plus or minus tolerance.

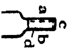
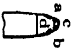
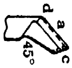
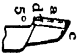
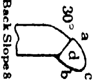
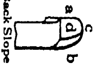
Tolerance, Unilateral—Permissible variation in one direction only, either a plus or minus, but not both.

Tool, Diamond—Black diamond set in metal for truing emery or other abrasive wheels. Also used for cutting metal.

Tool Holder, Lathe or Planer—A body or shank, adapted to hold small pieces of tool steel for cutting tools. These can be removed for sharpening or renewal without moving the holder and saves resetting the tool to the work.



TOOLS, LATHE—WM. SELLERS & CO.

Lathe																							
uare Thread  Right			60° V Thread  Right				Bent Side  Right				Side  Right				Bent Roughing  				Roughing  				Kind of Tool
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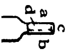
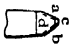
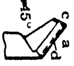
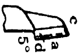
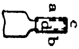
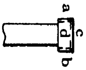
6°	0°	10°	0°	15°	7°	12°		12°	6°	6°		12°	6°	6°	22°	6°		5°	22°	6°		5°	Clearance
uare Thread  Left			60° V Thread  Left				Bent Side  Left				Side  Left				Nicking  				Finishing  				Kind of Tool
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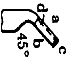
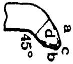
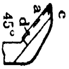
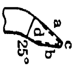
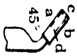
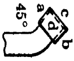
uare Thread Bent  Right			60° V Thread Bent  Right				Inside Bent  Left				Bent Brass  Right				Bent Nicking  Left				Bent Finishing  Left				Kind of Tool
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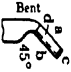
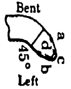
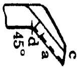
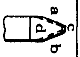
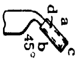
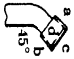
6°	0°	10°	0°	15°	7°	12°		12°	6°	6°	0°	10°	6°	10°	1°	6°	3°	3°	15°	6°	4°	4°	Clearance
uare Thread Bent  Left			60° V Thread Bent  Left				Inside Bent  Right				Brass  				Bent Nicking  Right				Bent Finishing  Right				Kind of Tool
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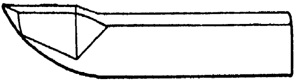
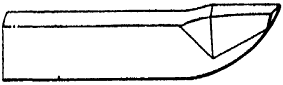
6°	10°	0°	0°	15°	12°	7°		12°	6°	6°	0°	10°	6°	10°	1°	6°	3°	3°	15°	6°	4°	4°	Clearance

TOOLS, LATHE



Left-hand Side Tool



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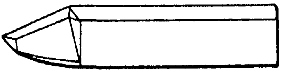

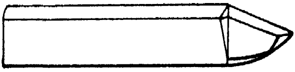

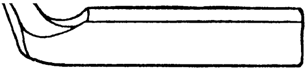
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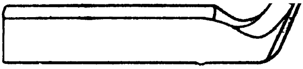
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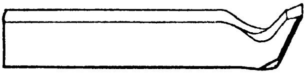
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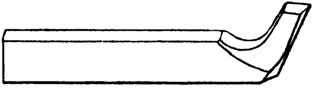
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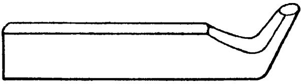
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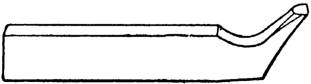
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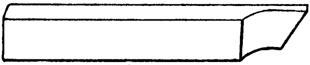
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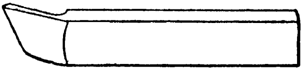
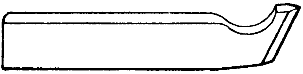
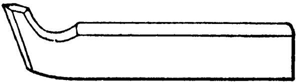
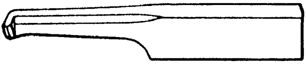
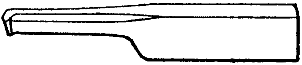
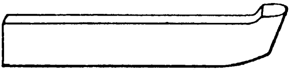

Bent Cutting-Off Tool.

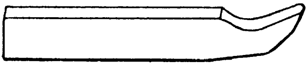

Straight Threading Tool.

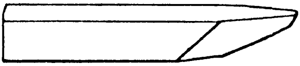

Bent Threading Tool.


Inside Boring Tool.


Inside Threading Tool.


Bull Nose Tool.


Finishing or Necking Tool.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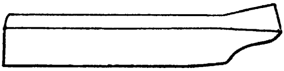
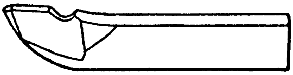
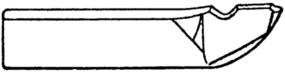
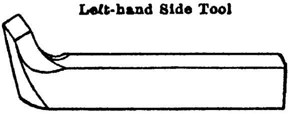
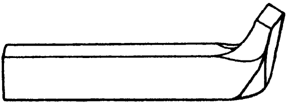

For Trueing Up Centers, &c.

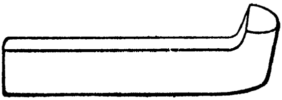
TOOLS, PLANER

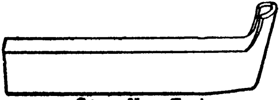

Left-hand Side Tool

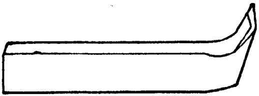

Right-hand Side Tool

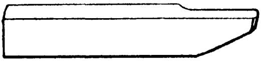

Left-hand Diamond Point Tool.

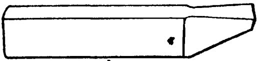

Right-hand Diamond Point Tool

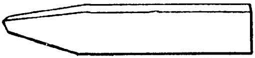

Bull Nose for Heavy Cuts.

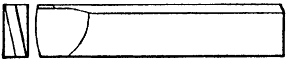

Gouge Nose Tool

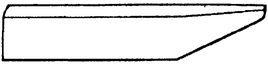

Broad Nose or Stocking Tool.

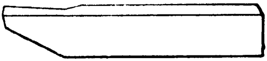

Right-hand Siding Tool.


For Finishing in Corners.


Left-hand Bevel Tool.


For Smoothing Wrought Iron or Steel.


Scaling Tool.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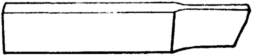
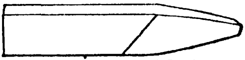
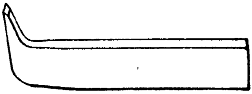
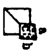
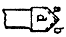
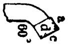
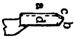
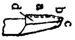
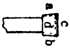
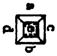
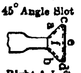
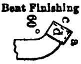
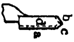
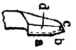
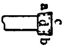
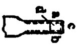
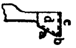
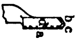
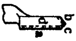
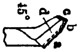
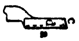
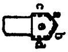
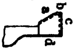
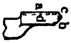
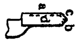
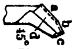
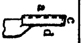

Cutting-Off Tool

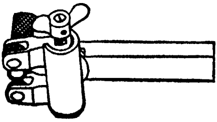

Right-hand Bevel Tool.


Smoothing Tool for Cast Iron

TOOLS, PLANER AND SLOTTER

Slotter	Planer					
Corner 	Chamfering 	Bent Finishing  Right	30° Angle  Right	Side Finishing  Right	Finishing 	Kind of Tool
End c Side b Side a	Top d Side b Side a	Top d End c Side a	Top d End c Side b Side a	Top d End c Side b Side a	Top d End c Side b Side a	Face
7° 4° 4°	0 4° 4°	7° 4° 3°	0° 4° 4° 6°	1 3/5° 6° 4° 6°	7° 4° 3° 3°	Clearance
Square 	45° Angle Slot  Right & Left	Bent Finishing  Left	30° Angle  Left	Side Finishing  Left	Splining 	Kind of Tool
End e Side d Side c Side b Side a	Top f End e Side d Side c Side b Side a	Top d End c Side a	Top d End c Side b Side a	Top d End c Side b Side a	Top d End c Side b Side a	Face
0° 4° 4° 4° 4°	0° 4° 4° 4° 4° 4°	7° 4° 3°	0° 4° 4° 6°	1 3/5° 6° 4° 6°	8° 4° 2° 2°	Clearance
Splining 	30° Angle Slot  Left	45° Angle  Left	40° Angle  Left	Bent Side Finishing  Left	Cutting Down  Left	Kind of Tool
Top d End c Side b Side a	Top d End c Side b Side a	Top d End c Side b Side a	Top d End c Side b Side a	Top d End c Side b Side a	Top d End c Side a	Face
4° 8° 0.3° 0.3°	0° 4° 4° 4°	0° 4° 4° 6°	0° 4° 4° 6°	1 3/5° 6° 4° 6°	0° 4° 6°	Clearance
Hexagon  For Wrenches	30° Angle Slot  Right	45° Angle  Right	40° Angle  Right	Bent Side Finishing  Right	Cutting Down  Right	Kind of Tool
Top e Side d Side c Side b Side a	Top d End c Side b Side a	Top d End c Side b Side a	Top d End c Side b Side a	Top d End c Side b Side a	Top d End c Side a	Face
0° 4° 4° 4° 4°	0° 4° 4° 4°	0° 4° 4° 6°	0° 4° 4° 6°	1 3/5° 6° 4° 6°	0° 4° 6°	Clearance

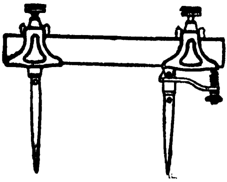
Tool, Knurling—For roughing or checking the outside of turned work so it can be readily grasped by hand. The tool is a wheel with the desired markings cut in the edge and hardened. It is forced against the work and actually forces the metal up into the depressions in the wheel. Some knurls are held in the end of a hand tool but for heavy knurling they are made to go in the tool post as shown.



Tools, Inserted Cutter—Holders in which are held small steel cutting tools. These are usually removed for grinding or replacing when broken or worn out. Now made of high-speed steel.

Tote Boxes or Pans—Pans or trays, usually of steel, for carrying or storing small parts.

Train—A series of gears, as the feed train of a lathe connecting spindle with lead screw. Also applied to series of levers.

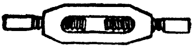


Trammels—For drawing large arcs or circles or for laying out center distances. Frequently called "trams." Fit on a beam and their capacity depends on the length of the beam.

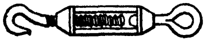
Trepanning Tool—Tool for cutting an annular groove outside or around a bored hole.

Tripper—Device that trips any piece of mechanism at the desired time. An example is found in conveyers where the tripper dumps the material at the desired point.

Tumbler Gear—An intermediate gear which meshes in between other gears to reverse the direction of the driven gear of the train.



Stub End



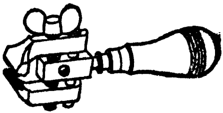
Hook and Eye

Turn Buckle—Really an elongated nut for connecting and tightening truss rods, tie rods, etc., used in construction work. Some have right- and left-hand threads as at top. Others thread in one end only.

Tuyere—The pipe or opening into forge through which air is forced.

V

Vise, Drill—Vise for use on drill press to hold work being drilled.



Vise, Hand—A small vise to be held in the hand. For small work that requires turning frequently to get at different sides.

Vise, Jig—A drill vise with arms which carry bushings so that pieces can be drilled in duplicate without special jigs for them.

Vise, Pin—Small hand vise for holding small wire rods.

V's—Ways shaped like a V, either raised above the bed, as on a lathe, or cut below, as in a planer, for guiding the travel of a carriage or table.

W

Washer, Open—Washers with one side open so as to be removed or slipped under the nut to avoid necessity of taking the nut entirely off. Also called a "C" washer.

Watt—The unit of electrical power and equals volts multiplied by amperes. 746 watts are equal to 1 horse power.

Ways—The guiding or bearing surfaces on which moving parts slide, as in a lathe plane or milling machine. The ways may be of any form, flat, V, or any other shape.

Welding—The joining of metals by heating the parts to be joined to the fusing point. Welding in an open fire is usually confined to iron and steel, but nearly all metals can be joined by electric or oxyacetylene welding.

Welding, Butt—Welding two pieces end to end, without overlap. By electricity the parts are heated to the fusing point and forced into close contact. By flame welding the edges are beveled and metal melted into the openings.

Welding, Lap—Pieces are lapped, and the contact surfaces welded by heat and pressure.

Welding, Shot—An electric process patented by Budd whereby a welding current is "shot" through the sheets in contact at very frequent intervals, welding the sheets at these points. It can be practically continuous, or "seam" welding. Generally used on thin sheet metal.

Welding, Spot—Electric welding by current passed through the parts between the contact points when pressure is applied. Largely used in place of riveting, as each spot is practically a rivet.

Wind—Pronounced with a long *i* as in "mind" and refers to a twist or warping away from straightness and parallelism.

Work Bench—Bench for handwork with vise, or for assembly. Usually 33 to 35 inches from floor and about 30 inches wide. Now largely made of metal, usually with wood or linoleum top.

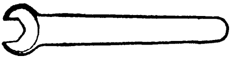
Wrench, Bridge Builders'—Large heavy wrench with a hole in end for a tackle to apply power.

WRENCHES, MACHINE:

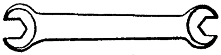
A variety of wrenches are illustrated herewith, and the usual name given.

A 15-degree angle opening permits the turning of a hexagon nut completely around where the swing of the handle is limited to 30 degrees.

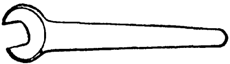
A 22½-degree angle opening permits the turning of any square head bolt or screw completely around where the swing of the handle is limited to 45 degrees.



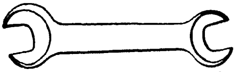
Single End, Hex.



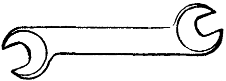
Double End, Hex.



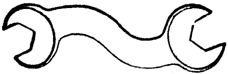
15° Angle, Single End



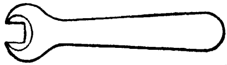
15° Angle, Double End



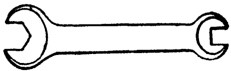
22½° Angle, Double End



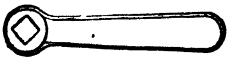
S — 22½° Angle



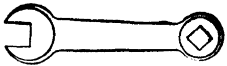
Single End, Set Screw and Machine



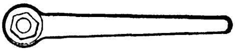
Double End, Set Screw and Machine



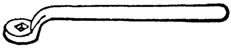
"Box"-Tool Post



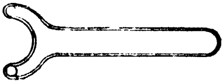
Double End, Tool Post



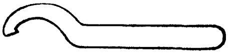
Hex. Box, 15° Angle



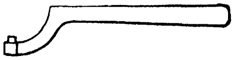
Chuck



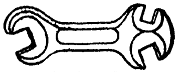
Pin-face, For Round Nuts Having Holes in their Face to Receive the two Wrench Pins



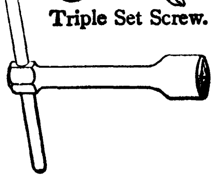
Hook Spanner, Milled out to suit Round Nuts Having Notches in the Periphery to Receive the Hook at the End of Spanner



Pin Spanner Used on Round Nuts which have Holes in the Periphery to receive the Spanner Pin

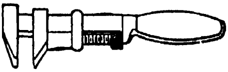


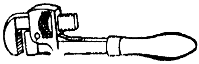
Triple Set Screw.

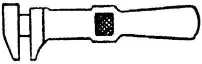


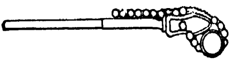
Socket

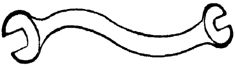
WRENCHES, MISCELLANEOUS

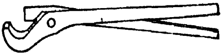

Monkey or Screw

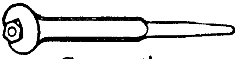

Stillson Pipe

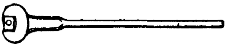

Pocket Adjustable

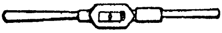

Vulcan Chain Pipe


General Utility


Pipe Tong


Construction


Track



Wrench, Tap—Wrench for holding and turning taps. Usually made adjustable for different sizes.

Wringing Fits—See Calipering and Fitting.

Unfinished drop-forged wrenches are plain forgings, with openings milled to fit the nut or screw on which they are to be used.

Semifinished wrenches are milled to fit the nut or screw on which they are to be used and case hardened all over.

Finished wrenches are milled to fit the nut or screw on which they are to be used and are ground, polished, case hardened all over, lacquered, with heads bright.

WARTIME DATA SUPPLEMENT

SECTION I

MATERIALS

Amola Steel.—Amola steels were developed by the late C. Harold Wills for the Chrysler Corporation to duplicate the physical properties of chrome-vanadium steels at a lower cost, using balanced proportions of molybdenum, manganese, and silicon. The S.A.E. 4000 series is part of this development. In the proper proportions these steels include properties that permit their use for cold heading and forgings, spring steel, ball and roller-bearing steel, tool steels for shear blades, cold chisels, axes, and razor blades. They were first used commercially in 1933.

TABLE 1.—DRILL SPEED FOR AMPCO METALS OF DIFFERENT GRADES

Ampco Grade	Tool Material	Roughing		Finishing	
		Speed, in Feet per Minute	Feed, in Inches	Speed, in Feet per Minute	Feed, in Inches
12	Cobalt steel	200	$\frac{1}{32}$	300	$\frac{1}{64}$
12	Tungsten carbide			500	$\frac{1}{64}$
16	Cobalt	175	$\frac{1}{32}$	250	$\frac{1}{64}$
16	Tungsten carbide			400	$\frac{1}{64}$
18	Cobalt	175	$\frac{1}{32}$	250	$\frac{1}{64}$
18	Tungsten carbide			400	$\frac{1}{64}$
20	Cobalt	100	$\frac{1}{64}$	250	$\frac{1}{64}$
20	Tungsten carbide			350	$\frac{1}{64}$
21	Cobalt	100	$\frac{1}{64}$	200	$\frac{1}{64}$
21	Tungsten carbide			300	$\frac{1}{64}$
22	Cobalt	75	$\frac{1}{64}$	200	$\frac{1}{64}$
22	Tungsten carbide			300	$\frac{1}{64}$

Ampco Metal.—Ampco metal is a bronze alloy consisting of hard particles held in a softer matrix to give wear resistance. It is centrifugally cast and is used for bushings and wearing surfaces, gears, worm wheels, cams, and rollers. Grade 22 is very hard to machine.

Angles for turning tools, drills, and taps are shown in Fig. 1. For milling follow standard steel practice as to speeds and feeds. Teeth of cutters should be radial. Slow deep cuts to get under the skin are best for roughing. Cutting speeds and feeds are given in Table 1.

Softer grades, 12, 16, and 18, can use standard taps. For harder grades grind off the lead edges to make the edge radial. Drills for all grades should be ground a little off center to give added clearance, as shown in Fig. 1, as well as suggested point angle.

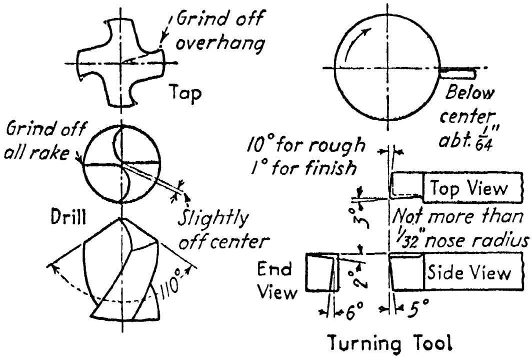


FIG. 1.

For grinding use resin-bonded silicon carbide wheels. Use a 30-grain wheel for rough work and a 60-grain wheel for finishing.

Kirksite.—Kirksite is a metal with about 94 per cent of very pure zinc, the remainder being aluminum, copper, and magnesium. It is lighter than lead and melts at about 717°F. It is widely used in airplane plants for forming dies for sheet-aluminum parts.

Magnesium and Aluminum Alloys.—Magnesium alloys are about two-thirds the weight of aluminum and one-fourth that of steel. Castings shrink $\frac{1}{8}$ inch per foot when large, $\frac{5}{32}$ inch when small. Sharp corners should be avoided both in castings and in machining, such as in spot facing. Thread lengths should be twice the diameter for National Coarse pitches and three times for fine (S.A.E.) threads.

Magnesium can usually be cut at the maximum speeds available on machine tools.

Oil-type coölants should be used for high speed and fine chips on account of fire hazard. A good coolant is three parts kerosene and one part lard oil. If fire occurs, smother it with an asbestos mat, powdered soapstone, or graphite, which should be kept in containers near machines. *Do not use water*, for it spreads the fire. Do not let chips accumulate on man or machine.

Grinding is best done with medium-hard wheels with clay bond and 30 to 46 grain. For snagging use 20 grain. When grinding must be done dry use high-suction exhaust fans with a capacity of 80 to 100 cubic feet per second. Grindings should be precipitated in water on account of fire hazard. Grinding wheels should be marked "For Magnesium Only."

Punch and die clearance should be small, 0.0015 inch being recommended for small sizes. Concaving the punch 3 degrees gives a smoother sheared edge. On sheets thicker than 0.065 inch, heating the sheet to 500 to 600°F. gives a smoother edge. The contraction after cooling must be allowed for in the punch.

Dies for forming magnesium are usually heated either by gas or by electricity. In either case the heat must be kept at a uniform temperature over the entire die surface.

The die surface should be kept well lubricated. A good mixture is 20 per cent graphite in tallow. Parts may be cleaned with a solution of 8 per cent chromic acid, plus 5 per cent nitric acid. A dip of 3 to 5 minutes at room temperature is usually enough. A 15 per cent chromic solution at boiling temperature can also be used. These fumes should be drawn off by ventilation, for they harm nasal passages. A tank of pure aluminum is necessary.

Thin magnesium sheets may be blanked and punched in the same way as other metals. When over 0.064 inch thick they may show a flaky fracture unless dies have very small clearance. Thicker sheets should be heated to 500°F., but the shrinkage must be allowed for in the punch and die.

For bends of 90 degrees the sheets should be heated to 350 or 400°F. for a radius of four times the sheet thickness. For a radius equal to the thickness of the sheet, a temperature of 600°F. is necessary.

MEEHANITE AND ITS HEAT-TREATMENT

Meehanite is a processed cast iron produced under rigidly controlled metallurgical conditions. Meehanite castings are made in a chain of foundries, under license to produce work from this metal. Castings have been used for the past 15 years in the construction of many types of machinery and industrial equipment with distinct advantages to the purchaser. Meehanite responds readily to heat-treatment and permits the achievement of high physical properties, accompanied by either hardness or machinability.

Three of the different heat-treatments that may be applied successfully to Meehanite castings are: (1) annealing for stress relief; (2) quench and draw; (3) annealing for machinability, and also machinability in the as-cast condition.

Stress relieving of Meehanite is carried out at temperatures ranging from 850 to 1150°F., depending upon the density of the iron. In this treatment, care must be taken to see that the casting is not overheated. Overheating causes a marked deterioration in the internal structure, with a resultant loss of strength.

A casting heated at 1100°F. for 1 hour per inch of section will have only a slight drop in tensile strength and hardness. Yet this temperature will remove any stress present in the casting and accomplishes the same results as the old process known as "aging," which was the practice of exposing iron castings to weather temperatures for a period of from 6 to 8 months.

Quenching and Drawing.—This treatment consists of heating the Meehanite casting slowly to 1100°F. and then transferring the casting to a furnace heated to 1575 to 1600°F. When the casting blends with the furnace, it is held at this temperature for 20 minutes per inch of section and then quenched in oil or water, preferably oil. Withdraw it from the quenching tank while warm—about 300°F — and temper immediately. Draw temperatures depend upon the hardness or tensile strength required. Table 2 shows the results of draws at different temperatures on castings having an original tensile strength of 52,000 pounds per square inch.

TABLE 2.—RESULT OF DRAWS AT DIFFERENT TEMPERATURES ON MEEHANITE

Draw Temperature, °F.	Strength	Brinell Hardness Number
570	72,000	450
750	78,000	430
900	75,000	335
1000	73,000	291
1200	60,000	256
1300	52,000	234
1400	47,000	207

PLASTICS

Plastics for Dies.—Two classes of plastics are used in making forming dies. Thermoplastics may be softened at any time by applying heat. Thermosetting plastics take a permanent set after their first heating.

Catalin.—This is a cast phenolic resin that is noninflammable. It weighs 0.048 pound per cubic inch. It can be tumbled to remove tool marks and sharp edges. Its strength varies from 3,000 to 6,000 pounds per square inch.

Turning.—A zero or negative cutting rake with 10- to 20-degree clearance should be used for Catalin. Set tool 1 or 2 degrees above center. A honed tool gives smoother cuts. Dust and shavings should be removed by a blower system. Cutting speed is about 600 feet per minute.

Drilling.—Drills for Catalin should have a slight negative rake on the cutting edge and have large flutes for chip clearance. For self-tapping screws use drill one or two sizes smaller than screw.

Threading.—For coarse threads use thread milling machine for best results.

Cutting Off.—Abrasive cutting-off disks should be from 6 to 20 inches in diameter. A thickness of 0.040 to $\frac{1}{16}$ inches and usual wheel speeds are suggested.

Sawing.—Use band saws with 14 to 18 teeth per inch at 1,200 to 1,500 feet per minute or more.

Lucite.—Lucite is a methyl-methacrylate resin that is very clear and transparent.

Drilling.—Standard drills can be used, but best results are obtained with drills having a flute angle of 17 degrees, a lip angle of 70 degrees, and a lip clearance of from 4 to 8 degrees. The drill lands, or margins, should be polished. Flat drills can be used for drilling thin sheets. Hollow-end mills are also good for thin stock. A good drill speed is about 120 feet per minute, with plenty of mild soap solution as a lubricant. Feed should be decreased as the hole gets deeper.

Threading.—Strong coarse-pitch threads are recommended instead of sharp V's. The tap can be run at about 75 per cent of the speed used on brass.

Plexiglas.—Plexiglas is an acrylic synthetic resin that is clearly transparent. It is derived from coal, petroleum, and water. It should be stored in a moderately moist and ventilated place, below 120°F., away from direct sun rays. Cutting tools should have no rake. Oil or water coolants are permissible but not necessary. Feeds should be constant; if they stop the material burns.

Sawing.—Use any fine-tooth saw good for wood or metal. For thick material every fifth tooth should be ground to clear the material from the cut. Run saws 8,000 to 12,000 feet per minute with fairly slow feed. Routers can run from 10,000 to 20,000 r.p.m.

Drilling.—Use regular drills but with very little lead on cutting edge. Withdraw drill frequently. Use light feed pressure.

Tapping.—Back tap out often to clear chips.

Forming.—Plexiglas is pliable at 220 to 300°F. Heat to temperature from 15 to 20 minutes, then allow surface to cool for 1 or 2 minutes before forming.

Cementing.—Use special cements recommended by makers.

NATIONAL EMERGENCY (N.E.) STEELS

Shortages, caused by the demand for war purposes, of the alloys used in steels that are normally used to secure certain desired characteristics have led to the substitution of different steels in places where they can be safely used. Some of these steels, known by different trade names, use no chromium, vanadium, tungsten, or manganese, and only a small portion of molybdenum. These are known as graphitic steels and have good wearing qualities when properly oil-hardened. Some of these steels machine very freely.

Recommended Substitute Steels for Materials Containing Nickel, Chromium, and Vanadium.—In view of the critical situation on the three alloys, namely, nickel, chromium, and vanadium, it is highly desirable that all specifications be revised as far as possible so as to eliminate these scarcer alloys in order that their consump-

TABLE 3.—NATIONAL EMERGENCY STEELS

CARBURIZING GRADES		
	Recommendation 1	Recommendation 2
A-1320	A-4027	8024
A-2317	8024	A-4027
A-2515	None	None
A-3120	A-4027	8024
E-3310	None	None
A-4119	A-4027	8024
A-4120	A-4027	8024
A-4320	None	8124
A-5120	A-4027	8024
A-6120	A-4027	8024
SEMI-′		
A-1330	A-4037	8233
A-2330	8233	A-4037
A-3130	A-4037	8233
A-4130	A-4037	8233
A-5130	A-4037	8233
S.A.E. 6130	A-4037	8233
THOROUGH-HARDENING GRADES (1) Sizes up to 3-inch round, inclusive, or equivalent (2) Sizes over 3-inch round, or equivalent		
A-1340	A-4047 (1)	8245
	A-4063 (2)	8447
A-2335	8339 (1)	None
	8447 (2)	None
A-2340	8442 (1)	None
	8447 (2)	None
S.A.E. 2345	8447 (1)	None
	8547 (2)	None
S.A.E. 2350	8547 (1)(2)	None
A-3045	8442 (1)	A-4068 (1)
	8447 (2)	None (2)
A-3135	8339 (1)	None
	8442 (2)	None
A-3140	8442 (1)	None
	8447 (2)	None
A-3141	8447 (1)	None
	8547 (2)	None

TABLE 3.—NATIONAL EMERGENCY STEELS.—*Continued*

	Recommendation 1	Recommendation 2
A-3145	8447 (1)	None
	8547 (2)	None
A-3150	8547 (1)(2)	None
A-3240	8442 (1)	None
	8447 (2)	
S.A.E. 3250	8547 (1)(2)	None
A-4137	8339 (1)	A-4063 (1)
	8442 (2)	None (2)
A-4142	8442 (1)	A-4068 (1)*
	8447 (2)	None (2)
A-4145	8447 (1)	A-4068 (1)*
	8547 (2)	None (2)
A-4150	8547 (1)(2)	A-4068 (1)*
		None (2)
A-4340	None	None
A-4640	8339 (1)	None
	8447 (2)	None
A-4645	8447 (1)	None
	8547 (2)	None
A-4650	8547 (1)	None
	None (2)	None
A-5045	A-4063 (1)	8339 (1)
	A-4068 (2)	8442 (2)
S.A.E. 5140	8339 (1)	A-4063 (1)
	8442 (2)	A-4068 (2)
A-5145	8442 (1)	A-4068 (1)
	8447 (2)	None
A-5150	8447 (1)	A-4068 (1)
	8547 (2)	None (2)
S.A.E. 6140	8339 (1)	A-4063 (1)*
	8442 (2)	A-4068 (2)
A-6145	8442 (1)	A-4068 (1)*
	8447 (2)	None
A-6150	8447 (1)	A-4068 (1)*
	8547 (2)	None (2)
A-9260	A-4068 (1)	None
	None (2)	

* First recommendation for small tools.

tion may be kept to a minimum except where such alloys are more drastically required in the execution of orders for defense materials.

The American Iron and Steel Institute suggests alternate grades for the A.I.S.I. steels containing nickel, chromium, and vanadium. Three alternates are included, namely, carbon-molybdenum of the

40 series, manganese-molybdenum (designated as 80, 81, 82, 83, 84, and 85 series), and nickel-chromium-molybdenum (designated as 86, 87, 88, and 89 series). The last grade is not applicable to orders without suitable priority, and so it will not be considered in our recommendations.

Since subsequent decisions by the W.P.B. may change these views, the following alternates may be of a temporary nature.

Although the A.I.S.I. has considered size in its recommendations, it was the consensus that we grade Thorough-Hardening steels for sizes up to 3-inch round, inclusive, and above 3-inch round or equivalent. This is not necessary for carburizing and semi-Thorough-Hardening grades.

These recommendations are based solely on metallurgical considerations and are classified as first and second choice. Customers have the prerogative of specifying either grade. Where no recommendations are made, it is believed that no suitable substitute is available.

PROPERTIES GIVEN TO STEEL BY ALLOYING ELEMENTS

Application of elements to iron to produce steels of varying qualities is strikingly similar to the application of drugs in medicine. Each element has separate and often powerful effects, with frequently other effects in combination with additional elements. Like drugs, they may be beneficial in tiny quantities, but ruinous in great quantities unless neutralized or checked by supplemental elements.

An understanding of the chief characteristics given to steel by the elements is an aid to a better selection and use of steels, especially in tool use.

Aluminum.—Deoxidizer. Restricts grain growth by forming dispersed nitrides and oxides. Forms hard nitrides when heated in contact with nitrogen, making extremely hard steel. Small amounts increase strength, but large amounts embrittle steel. From 2 to 5 per cent gives heat resistance and oxidation resistance.

Carbon.—Hardener, by forming Fe_3C under heat-treatment. Increases strength rapidly up to saturation point of 0.85 per cent, above which the steel becomes increasingly brittle unless there are other elements besides iron to take up the carbon. Forms hard carbides with iron, chromium, vanadium, increasing strength and wear resistance. Even slightest additions decrease the ductility.

Chromium.—Forms hard carbides. Gives very deep hardening and great wear resistance. Small amounts toughen steel, increasing strength and impact resistance. Decreases machinability. Decreases hardening range unless balanced with nickel. Retains hardness at more elevated temperatures than iron carbide. Gives slight red hardness.

Cobalt.—Adds red hardness. Retains hard carbides at high temperatures, but tends to decarburize steel in heat-treatment. Increases hardness and tenacity, but considerable amounts decrease impact resistance. Increases residual magnetism and coercive magnetic force of steel for magnets.

Columbium.—Used to minimize intergranular corrosion in stainless steels. Has carbide-forming properties increasing strength and hardness, but not used generally for the purpose. Softening effect shortens time of annealing of high-chromium steels.

Lead.—Forms minute strings and finely divided particles. Minute quantities give free machining without imparting the weakening effect of sulphur.

Lithium.—Combines easily with oxygen, hydrogen, sulphur, to form low-melting-point compounds which pass off as gases. Powerful deoxidizer and degasifier. Lithium treatment increases elastic limit of carbon steels. Increases fluidity of stainless steels to produce dense castings with high yield point.

Manganese.—Deoxidizer and desulphurizer. Even minute amounts increase hardness, wear resistance, and strength. Raises solubility of the carbon. Lowers critical point and widens hardening range, thus permitting a less drastic treatment in oil. Air hardening begins at about 1.5 per cent. Makes steel austenitic at about 12 per cent. High-manganese steel work hardens and is nonmagnetic. Increases coefficient of expansion. Small amounts increase depth of hardening and speed of hardening. Decreases tendency to distort under heat-treatment. Intermediate amounts produce brittleness unless other elements are present.

Molybdenum.—Adds red hardness. Increases strength and impact resistance at high temperatures, but hardens and embrittles at low temperatures. Retards grain growth. Gives deep hardening and widens hardening range. Increases creep resistance and resistance to deformation at moderate temperatures. Goes into solid solution, but when other elements are present forms hard carbides. In aluminum steels small amounts reduce temper brittleness. Increases machinability of carbon steels. Increases corrosion resistance of stainless steels at high temperature.

Nickel.—Increases hardness, strength, ductility, and impact resistance. Narrows hardening range, but lowers critical point, reducing danger of warpage and cracking. Refines structure. Retards grain growth. Decreases machinability. Makes chromium steels austenitic. Balances the intensive deep-hardening effect of chromium. Large amounts give resistance to oxidation at high temperatures.

Nitrogen.—Normally undesirable. Hardens slightly and reduces ductility. Small amounts refine grain and increase strength of high-chromium steels. Forms hard nitrides with aluminum and, introduced externally into balanced aluminum-bearing steels, inhibits grain growth at high temperatures.

Phosphorus.—Promotes cold-shortness. Small amounts increase strength slightly and increase resistance to corrosion. Slight amounts decrease tendency of steel sheets to stick together.

Silicon.—Deoxidizer. Graphitizer. Throws carbon out of solution. Small amounts increase impact resistance, and up to 1.75 per cent increases elastic limit, but needs assistance of other carbide-forming elements. Strengthens low-alloy steels. Medium amounts increase magnetic permeability and decrease hysteresis loss. Forms hard iron silicides, and large amounts give great hardness, wear resistance, and acid resistance, but cause brittleness. Has wide range of utility if used with expert technique, especially in alloy steels.

Sulphur.—Forms soft and weak sulphides which weaken the steel and promote hot-shortness. Minute quantities advantageous to aid machinability.

Tantalum.—Used in some special steels to give increased resistance to scaling at high temperatures.

Tellurium.—Small amounts form sulphide which aids machining without making the steel hot short.

Titanium.—Deoxidizes and denitrogenizes. Increases strength and hardness. Fixes carbon in inert particles. Minimizes intergranular corrosion in high-chromium steels.

Tungsten.—Adds red hardness and stability of the hard carbides at high heats. Widens hardening range, and gives deep hardening. Increases strength and wear resistance. Small quantities produce fine grain structure, but large quantities embrittle the steel. Produces both a hard carbide and an iron tungstide. Large qualities, to produce full red hardness, must be supplemented by other carbide-forming elements. Forms hard abrasive-resistant particles in high-carbon steels. Adds acid resistance and corrosion resistance. Gives increased residual magnetism and greater coercive force in steel for magnets.

Uranium.—Increases elastic limit and strength of steels. Is powerful deoxidizer and denitrogenizer. Has carbide-forming qualities. Because of expense used only in some tool steels.

Vanadium.—Powerful deoxidizer. Toughens and strengthens steels. Forms hard carbides. Refines the grain. Widens hardening range. Retains hardness at higher temperatures than carbon steel. Reduces grain growth. Increases fatigue resistance and shock resistance. Forms double carbides with chromium, giving hard "keen-edge" quality to steel.

Zirconium.—Powerful deoxidizer and desulphurizer. Steels can be made without manganese by use of zirconium. Carries off nitrogen. Makes uniformity of grain and produces ductility and shock resistance. Small amounts of residual zirconium form zirconium sulphide which aids machinability and rolling. Reduces aging fatigue in steel.

SCRAP RATIO IN METAL PRODUCTION

The part scrap plays in production is not generally realized. Figures for 1941 show the importance of scrap. Steel production for that year of 82,500,000 net tons of ingots required the use of 44,600,000 net tons of scrap. An additional 17,000,000 tons of iron and steel scrap was consumed by iron foundries and blast furnaces in making pig iron and other iron products. Thus a total of about 61,000,000 tons, or about half of the raw material required to make steel and iron products for the year, was iron and steel scrap. Of this total 27,000,000 tons (or 44 per cent) was "purchased" scrap produced outside the steel industry itself and collected from general public sources.

Table 4 shows roughly the importance of scrap in 1941 to the total production of other critical metals and rubber. The aluminum figure includes scrap recovered within the producing plant.

TABLE 4.—IMPORTANCE OF SCRAP

Material	Total 1941 New Supply, in Tons	Total Scrap in 1941 New Supply, in Tons	Ratio of Scrap to Total, Per Cent
Aluminum	416,000	94,000	23
Antimony	47,600	21,600	46
Copper—refined	2,117,500	360,000	17
Lead (including antimonial lead)	1,090,019	213,674	20
Nickel	101,850	11,550	11
Tin	178,528	20,160	11
Zinc	923,300	65,400	7
Rubber	1,441,000	310,000	21

W.P.B. Report, July 13, 1942.

MACHINING STAINLESS STEEL

Since stainless steel is used in much war material its peculiarities should be understood. The general practice recommended by W. B. Brooks, formerly with the Carnegie-Illinois Steel Company, is summed up in the following: "Use liberal cutting rake and clearance. Use sulphur and sulphur chlorine cutting fluids liberally. Use first-quality high-speed tools. Support the tools rigidly. Keep the tools sharp and smooth; hone after grinding. Use a generous feed and cut below the work-hardened surface left by the preceding cut. Use rigid equipment with plenty of power for continuous cutting. Use cutting speeds 20 to 50 per cent lower than for machine steels."

SECTION II

SCREW THREADS

ACME THREADS

Gages for Acme Threads.—Both "go" and "not go" gages, representing the extreme product limits, are necessary for the proper inspection of Acme screw threads.

TABLE 1.—TOLERANCES FOR "GO" AND "NOT GO" THREAD GAGES, ACME THREADS

Threads per Inch	Tolerance on Thread Thickness at Basic Pitch Line		Tolerance in Lead	Tolerance on Half Angle of Thread		Tolerance on Major Diameter		Tolerance on Minor Diameter	
	From	To				From	To	From	To
1	2	3	4	5		6	7	8	9
	Inches	Inches	Inches ±	Deg. ±	Min. ±	Inches	Inches	Inches	Inches
16	0.0000	0.0002	0.0005	0	10	0.0000	0.0003	0.0000	0.0003
14	0.0000	0.0002	0.0005	0	10	0.0000	0.0004	0.0000	0.0004
12	0.0000	0.0002	0.0005	0	10	0.0000	0.0004	0.0000	0.0004
10	0.0000	0.0002	0.0005	0	10	0.0000	0.0005	0.0000	0.0005
9	0.0000	0.0003	0.0005	0	10	0.0000	0.0005	0.0000	0.0005
8	0.0000	0.0003	0.0005	0	5	0.0000	0.0006	0.0000	0.0006
7	0.0000	0.0003	0.0005	0	5	0.0000	0.0007	0.0000	0.0007
6	0.0000	0.0003	0.0005	0	5	0.0000	0.0008	0.0000	0.0008
5	0.0000	0.0004	0.0005	0	5	0.0000	0.0010	0.0000	0.0010
4	0.0000	0.0004	0.0005	0	5	0.0000	0.0010	0.0000	0.0010
3½	0.0000	0.0004	0.0005	0	5	0.0000	0.0010	0.0000	0.0010
3	0.0000	0.0005	0.0005	0	5	0.0000	0.0010	0.0000	0.0010
2½	0.0000	0.0005	0.0005	0	5	0.0000	0.0010	0.0000	0.0010
2	0.0000	0.0006	0.0005	0	5	0.0000	0.0010	0.0000	0.0010
1½	0.0000	0.0006	0.0005	0	5	0.0000	0.0010	0.0000	0.0010
1¼	0.0000	0.0007	0.0005	0	5	0.0000	0.0010	0.0000	0.0010
1	0.0000	0.0008	0.0005	0	5	0.0000	0.0010	0.0000	0.0010

Table 1 is given here for the purpose of establishing definite limits for gages used in the inspection of Acme threads, rather than for the purpose of specifying the gages required for the various inspection operations. The dimensions of gages should be in accordance with the principles (1) that the "go" gage should check simultaneously as many elements as possible and a "not go" gage can effectively check but one element; and (2), that permissible variations in the gages be within the extreme product limits.

1. *Tolerances on Lead.*—The tolerances on lead given in Table 1 are specified as an allowable variation between any two threads not farther apart than 12 inches.

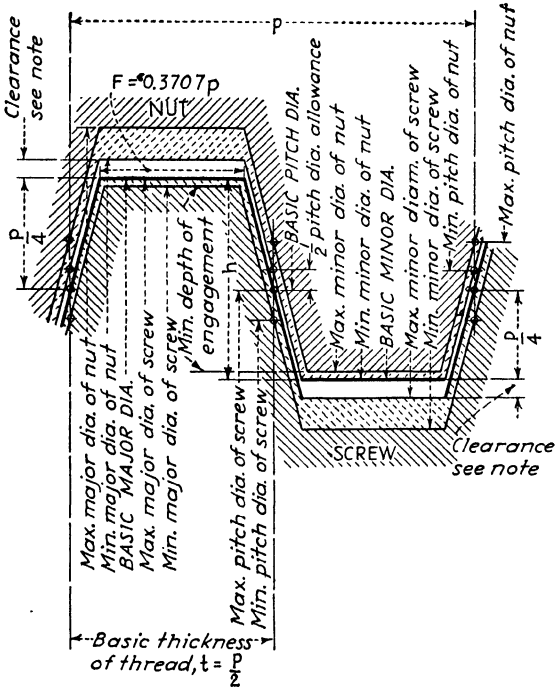


FIG. 1.—Acme thread dimensions.

2. *Tolerances on Angle of Thread.*—The tolerances on angle of thread, as specified in Table 1 for the various pitches, are tolerances on *one-half* of the included angle. This ensures that the bisector of the included angle will be perpendicular to the axis of the thread within proper limits. The equivalent deviation from the true thread form caused by such irregularities as convex or concave sides of thread, or slight projections on the thread form, should not exceed the tolerances permitted on angle of thread.

TRANSLATING THREAD STANDARDS

American Standard ASA B1.3-1941 on Acme and other translating threads was designated as an American Standard in September, 1941.

TABLE 2.—GENERAL-PURPOSE ACME THREAD—SCREWS
Detail Dimensions and Tolerances for Recommended Diameter and Pitch Combinations
(Dimensions in Inches)

Size	Threads* per Inch	Major Diameter		Pitch Diameter		Minor Diameter		Pitch§ Diameter Tolerance in Terms of Thread Thickness Variation	Helix Angle	
		Max. (Basic) D	Min.†	Max. (Basic) E	Min.	Max.‡	Min.†		Deg.	Min.
$\frac{1}{4}$	16	0.2500	0.2469	0.2187	0.2087	0.1775	0.1744	0.0026	5	12
$\frac{5}{16}$	14	0.3125	0.3089	0.2768	0.2668	0.2311	0.2275	0.0026	4	42
$\frac{3}{8}$	12	0.3750	0.3708	0.3333	0.3233	0.2816	0.2774	0.0026	4	33
$\frac{7}{16}$	12	0.4375	0.4333	0.3958	0.3858	0.3441	0.3399	0.0026	3	50
$\frac{1}{2}$	10	0.5000	0.4950	0.4500	0.4400	0.3800	0.3750	0.0026	4	3
$\frac{5}{8}$	8	0.6250	0.6187	0.5625	0.5495	0.4800	0.4737	0.0034	4	3
$\frac{3}{4}$	6	0.7500	0.7417	0.6667	0.6537	0.5633	0.5550	0.0034	4	33
$\frac{7}{8}$	6	0.8750	0.8667	0.7917	0.7757	0.6883	0.6800	0.0041	3	50
1	5	1.0000	0.9900	0.9000	0.8840	0.7800	0.7700	0.0041	4	3
$1\frac{1}{8}$	5	1.1250	1.1150	1.0250	1.0060	0.9050	0.8950	0.0049	3	33
$1\frac{1}{4}$	5	1.2500	1.2400	1.1500	1.1310	1.0300	1.0200	0.0049	3	10
$1\frac{3}{8}$	4	1.3750	1.3625	1.2500	1.2280	1.1050	1.0925	0.0057	3	39
$1\frac{1}{2}$	4	1.5000	1.4875	1.3750	1.3530	1.2300	1.2175	0.0057	3	19
$1\frac{3}{4}$	4	1.7500	1.7375	1.6250	1.6000	1.4800	1.4675	0.0065	2	48
2	4	2.0000	1.9875	1.8750	1.8470	1.7300	1.7175	0.0072	2	26
$2\frac{1}{4}$	3	2.2500	2.2333	2.0833	2.0523	1.8967	1.8800	0.0080	2	55
$2\frac{1}{2}$	3	2.5000	2.4833	2.3333	2.2993	2.1467	2.1300	0.0088	2	43
$2\frac{3}{4}$	3	2.7500	2.7333	2.5833	2.5463	2.3967	2.3800	0.0096	2	21
3	2	3.0000	2.9750	2.7500	2.7100	2.4800	2.4550	0.0103	3	19
4	2	4.0000	3.9750	3.7500	3.7070	3.4800	3.4550	0.0111	2	26
5	2	5.0000	4.9750	4.7500	4.7070	4.4800	4.4550	0.0111	1	55

* The selection of threads per inch is arbitrary and is intended for the purpose of establishing a standard.

† These dimensions result in tolerances on major and minor diameters equal to 0.05p.

‡ Maximum minor diameter of a screw of a given pitch is such as to result in a flat at the root equal in inches to 0.3707p − (0.52 × clearance) when the pitch diameter of the screw is at its maximum value.

§ The length of gage should be equal to the length of engagement which in this case is one and one-half diameters.

This standard covers the design and dimensions of Acme and similar single screw threads intended primarily for translating screws. The designs included have been chosen with the dual purpose of meeting varied needs of the users to the greatest possible extent and at the same time establishing a product capable of economical production. The diameters and pitches have been selected with a view to meeting the present needs with the fewest number of items in order to reduce to a minimum the inventory of both tools and gages. The tolerances are such as to produce complete interchangeability and maintain a high grade of product.

Four series of translating screw threads are included in this standard—the general-purpose Acme, the 29-degree stub, the 60-degree stub, and a modified square thread. These screw thread series are intended to cover such applications as lathe dogs and clamps, track drills, steel bench vises, machine-tool vises, drill-press vises, lifting jacks, steel hand clamps, valve stems, cross-feed screws for lathes, letter-copy presses, and elevating screws on machine tools and other machines.

The subject of Acme and kindred threads embraces a wide field, and it is not possible to combine in a single standard all the variables of all the uses. The following applications are recognized as common usages, but each has special features that prevent inclusion in a general-purpose standard:

1. Feed and lead screws where backlash or end shake are objectionable. In such applications the nut is tapped first and then the screw is threaded to fit. The screw and nut so made are kept as a pair.
2. Long lead screws where sagging causes threads to seize. In such applications the major-diameter clearance is reduced so that bearing takes place at the major diameter before seizing can occur.
3. Assemblies where the thread must maintain some degree of alignment as well as transmit motion. In these applications a reduced major-diameter clearance is the most effective and economical means of obtaining satisfactory assemblies.
4. There is a considerable demand in mechanical industries for threaded assemblies that provide faster advance per revolution and give greater wear surface. The threaded forms covered by this specification are used frequently, incorporating changes in details to meet particular requirements. It is recommended that no coarser thread for a given diameter than those listed be used but instead that a multiple thread giving the desired lead be adopted. Many applications in the valve industry are typical. Where it is necessary to use multiple threads, the form of single thread corresponding to "crests per inch" of the multiple thread should be used.

In the Acme general-purpose thread the angle between the sides of the thread is 29 degrees. The threads are truncated top and bottom, give a basic depth and thickness of 0.50 of the pitch, and are symmetrical about a line perpendicular to the axis of the screw. This series should be used for all Acme thread applications except in special cases where design or operating considerations are such that the 29-degree stub, the 60-degree stub, or some other modified thread can be employed to better advantage. Basic dimensions of the Acme general-purpose thread are given in Table

31, page 48, "American Machinists' Handbook." Detailed dimensions and tolerances for recommended pitches for diameters from ¼ to 5 in. are given in Tables 2 and 3.

TABLE 3.—GENERAL-PURPOSE ACME THREAD—NUTS
Detail Dimensions and Tolerances for Recommended Diameter and Pitch Combinations
(Dimensions in Inches)

Size	Threads* per Inch	Major Diameter	Pitch Diameter		Minor Diameter		Pitch‡ Diameter Tolerance in Terms of Thread Thickness Variation	Helix Angle	
		Min.	Max.	Min.	Max.†	Min. (Basic) *K*		Deg.	Min.
¼	16	0.2600	0.2337	0.2237	0.1906	0.1875	0.0026	5	12
5/16	14	0.3225	0.2918	0.2818	0.2447	0.2411	0.0026	4	42
⅜	12	0.3850	0.3483	0.3383	0.2959	0.2917	0.0026	4	33
7/16	12	0.4475	0.4108	0.4008	0.3584	0.3542	0.0026	3	50
½	10	0.5200	0.4650	0.4550	0.4050	0.4000	0.0026	4	3
⅝	8	0.6450	0.5805	0.5675	0.5063	0.5000	0.0034	4	3
¾	6	0.7700	0.6847	0.6717	0.5917	0.5833	0.0034	4	33
⅞	6	0.8959	0.8127	0.7967	0.7167	0.7083	0.0041	3	50
1	5	0.0200	0.9201	0.9050	0.8100	0.8000	0.0041	4	3
1⅛	5	1.1450	1.0490	1.0300	0.9350	0.9250	0.0049	3	33
1¼	5	1.2700	1.1740	1.1550	1.0600	1.0500	0.0049	3	10
1⅜	4	1.3950	1.2770	1.2550	1.1375	1.1250	0.0057	3	39
1½	4	1.5200	1.4020	1.3800	1.2625	1.2500	0.0057	3	19
1¾	4	1.7700	1.6500	1.6300	1.5125	1.5000	0.0065	2	48
2	4	2.0200	1.9080	1.8800	1.7625	1.7500	0.0072	2	26
2¼	3	2.2700	2.1213	2.0903	1.9334	1.9167	0.0080	2	55
2½	3	2.5200	2.3743	2.3403	2.1834	2.1667	0.0088	2	43
2¾	3	2.7700	2.6273	2.5903	2.4334	2.4167	0.0096	2	21
3	2	3.0200	2.8000	2.7600	2.5250	2.5000	0.0103	3	19
4	2	4.0200	3.8030	3.7600	3.5250	3.5000	0.0111	2	26
5	2	5.0200	4.8030	4.7600	4.5250	4.5000	0.0111	1	55

* The selection of threads per inch is arbitrary and is intended for the purpose of establishing a standard.

† These dimensions result in tolerances on the minor diameter equal to $0.05p$.

‡ The length of gage should be equal to the length of engagement, which in this case is one and one-half diameters.

STUB THREADS

29-Degree Stub Threads.—The angle between the sides of the thread is 29 degrees as in the case of the general-purpose Acme thread; the threads are truncated top and bottom, but the basic depth of thread is reduced to 0.30 of the pitch. The basic thread thickness is one-half the pitch as before, and the threads are symmetrical about a line perpendicular to the axis of the screw. This produces a very strong thread section, and in addition a thread admirably suited to applications where space limitations or other economic considerations make a shallow thread desirable. Basic dimensions of the 29-degree stub thread are given in Table 4.

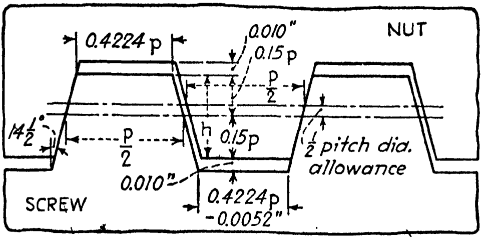


FIG. 2.—29-degree stub threads.

TABLE 4.—BASIC DIMENSIONS OF 29-DEGREE STUB THREADS (Dimensions in Inches)

Threads per Inch	Pitch, p	Depth of Thread (Basic), $h = 0.3p$	Total* Depth of Thread	Thread Thickness (Basic), $t = 0.5p$	Width of Flat at	
					Crest of Screw (Basic), $F = 0.4224p$	Root of Screw, $F_c = 0.4224p - (0.52 \times \text{Clearance})$
1	2	3	4	5	6	7
16	0.06250	0.0188	0.0238	0.0313	0.0264	0.0238
14	0.07143	0.0214	0.0264	0.0357	0.0302	0.0276
12	0.08333	0.0250	0.0300	0.0417	0.0352	0.0326
10	0.10000	0.0300	0.0400	0.0500	0.0422	0.0370
9	0.11111	0.0333	0.0433	0.0556	0.0469	0.0417
8	0.12500	0.0375	0.0475	0.0625	0.0528	0.0476
7	0.14286	0.0429	0.0529	0.0714	0.0603	0.0551
6	0.16667	0.0500	0.0600	0.0833	0.0704	0.0652
5	0.20000	0.0600	0.0700	0.1000	0.0845	0.0793
4	0.25000	0.0750	0.0850	0.1250	0.1056	0.1004
3½	0.28571	0.0857	0.0957	0.1429	0.1207	0.1155
3	0.33333	0.1000	0.1100	0.1667	0.1408	0.1356
2½	0.40000	0.1200	0.1300	0.2000	0.1690	0.1638
2	0.50000	0.1500	0.1600	0.2500	0.2112	0.2060

---

* A clearance of at least 0.010 inch is added to h on threads of 10-pitch and coarser, and 0.005 inch on finer pitches, to produce extra depth, thus avoiding interference with threads of mating part at minor or major diameters. It is recognized that there are conditions under which a greater or less clearance may be desirable.

60-Degree Stub Threads.—The angle between the sides of the thread is 60 degrees. The threads are truncated top and bottom, have a basic depth of 0.433 of the pitch, a basic thickness of one-half the pitch, and are symmetrical about a line perpendicular to the axis of the screw. Basic dimensions of the 60-degree stub thread are given in Table 5.

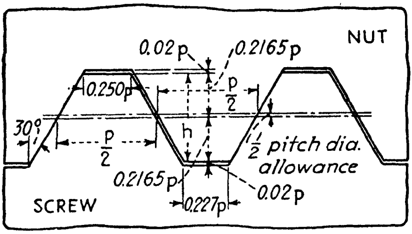


FIG. 3.—60-degree stub thread.

TABLE 5.—BASIC DIMENSIONS OF 60-DEGREE STUB THREADS
(Dimensions in Inches)

Threads per Inch	Pitch, p	Depth of Thread (Basic), $h = 0.433p$	Total* Depth of Thread, $(h + 0.02p)$	Thread Thickness (Basic), $t = 0.5p$	Width of Flat at Crest of Screw $F = 0.250p$	Width of Flat at Root of Screw $F_c = 0.227p$
1	2	3	4	5	6	7
16	0.06250	0.0271	0.0283	0.0313	0.0156	0.0142
14	0.07143	0.0309	0.0324	0.0357	0.0179	0.0162
12	0.08333	0.0361	0.0378	0.0417	0.0208	0.0189
10	0.10000	0.0433	0.0453	0.0500	0.0250	0.0227
9	0.11111	0.0481	0.0503	0.0556	0.0278	0.0252
8	0.12500	0.0541	0.0566	0.0625	0.0313	0.0284
7	0.14286	0.0619	0.0647	0.0714	0.0357	0.0324
6	0.16667	0.0722	0.0755	0.0833	0.0417	0.0378
5	0.20000	0.0866	0.0906	0.1000	0.0500	0.0454
4	0.25000	0.1083	0.1133	0.1250	0.0625	0.0567

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* A clearance of at least $0.02p$ is added to h to produce extra depth, thus avoiding interference with threads of mating part at minor or major diameters.

MODIFIED SQUARE THREADS

The angle between the sides of the thread is 10 degrees. The threads are truncated top and bottom, have a basic depth of 0.50

of the pitch, a basic thread thickness of 0.50 of the pitch, and are symmetrical about a line perpendicular to the axis of the screw. The angle of 10 degrees results in a thread that is the equivalent of a "square thread" insofar as all practical considerations are concerned and yet capable of economical production. This thread form is illustrated in Fig. 4.

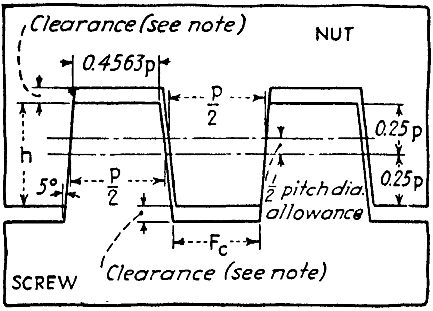


FIG. 4.—10-degree square thread.

Multiple-thread milling cutters and ground thread taps should not be specified for modified square threads of steep helix angle without consulting the cutting-tool manufacturer.

AMERICAN NATIONAL STANDARD GAS-CYLINDER THREADS

Gas-Cylinder Valve-Outlet Threads.—Standard sizes of threads for gas-cylinder valve outlets of various types are presented in Table 6. The purpose of these standards is to prevent cross connections of equipment used with a given type of valve with another type where such connection may be dangerous or undesirable, as well as to promote interchangeability among threads of a given type of valve.

Hose Connections for Welding and Cutting Torches.—Specifications covering hose connections for welding and cutting torches were formulated and adopted in 1925 by the International Acetylene Association, the Gas Products Association, and various manufacturers. Essentially the same specifications were adopted by the National Screw Thread Commission in 1926.

Revised specifications for these connections were adopted by the International Acetylene Association, Mar. 9, 1939. These revised specifications were adopted by the Interdepartmental Screw Thread Committee and are presented below.

Dimensions essential to the interchangeability of parts have been standardized. Other dimensions and details of design are optional, so that manufacturers may use their own judgment and follow their usual practice as much as possible. Four sizes of connections are specified, as illustrated in Table 7.

TABLE 6.—AMERICAN NATIONAL STANDARD GAS CYLINDER VALVE OUTLET THREADS (Dimensions in Inches)

Type of Cylinder Valve	Designation of Thread	Major Diameter		Pitch Diameter		Minor Diameter	Length of Thread
		Max.	Min.	Max.	Min.	Max.	Min.
1	2	3	4	5	6	7	8
Oxygen, carbon dioxide, or air	0.903″-14NS-3	0.9030	0.8932	0.8566	0.8530	0.8154	5/8
Hydrogen, nitrogen, or helium	0.830″-14NS-2LH	0.8300	0.8200	0.7836	0.7786	0.7424	5/8
Acetylene	0.835″-14NS-3	0.8350	0.8290	0.7780	0.7740	0.7368	5/8
Ethyl chloride	1/2″-14 NPS form	0.8350	0.8290	0.7780	0.7740		
Anhydrous ammonia	3/8″-18 NPT (internal)						
Dichlorodifluoromethane	3/4″-14 NPS form	1.031	1.025	.9717	0.9677		

All threads are external except for anhydrous ammonia, and all are right-hand except on valves for hydrogen, nitrogen, and helium.

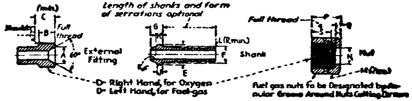

(min)
C
B
Full thread
A
60°
External Fitting
Length of shanks and form of serrations optional
G
H
L
L (R min)
F
E
Shank
Full thread
S
P
Q
N
Nut
M (Bore)
D- Right Hand, for Oxygen
D- Left Hand, for Fuel-gas
Fuel gas nuts to be Designated by Annular Groove Around Nuts Cutting Corners

Table 7.—American National Standard Hose Connections for Welding and Cutting Torches, Detail Dimensions for Classes *A*, *B*, *C*, and *D* (Dimensions in Inches)

Class	For Hose Sizes	External Fitting				Shank			
		A, Large Diameter of Seat	*B*, Length of Thread	*C*, Length to Shoulder	*D*, Thread Size, Class 3	*E*, Diameter of Shoulder	*F*, Diameter of Shank	*G*, Length to Shoulder	*H*, Radius Distance
1	2	3	4	5	6	7	8	9	10
A	$\frac{3}{16}$, $\frac{1}{8}$	0.250 ±0.005	$\frac{1}{4}$	$\frac{9}{32}$	$\frac{3}{8}$-24	0.326 ±0.002	0.248 −0.005	$\frac{1}{4}$	0.182 ±0.005
B	$\frac{3}{8}$, $\frac{5}{16}$, $\frac{1}{4}$, $\frac{3}{16}$, $\frac{1}{8}$	0.433 ±0.005	$\frac{5}{16}$	$\frac{13}{32}$	$\frac{9}{16}$-18	0.498 ±0.002	0.430 −0.005	$\frac{5}{16}$	0.175 ±0.005
C	$\frac{1}{2}$, $\frac{3}{8}$, $\frac{5}{16}$, $\frac{1}{4}$	0.625 ±0.005	$\frac{11}{16}$	$\frac{21}{32}$	$\frac{7}{8}$-14	0.750 ±0.004	0.578 −0.010	$\frac{7}{16}$	0.250 ±0.005
D	$\frac{3}{4}$, $\frac{5}{8}$, $\frac{1}{2}$, $\frac{3}{8}$	0.954 ±0.008	$\frac{7}{8}$	$\frac{31}{32}$	$1\frac{1}{4}$-12	1.136 ±0.004	0.875 −0.010	$\frac{5}{8}$	0.327 ±0.008

TABLE 7.—AMERICAN NATIONAL STANDARD HOSE CONNECTIONS FOR WELDING AND CUTTING TORCHES, DETAIL DIMENSIONS FOR CLASSES *A*, *B*, *C*, AND *D*.—*Continued*

(Dimensions in Inches)

Class	For Hose Sizes	Shank			Nut				
		J, Length of Shoulder	*K*, Radius	*L*, Radius	*M*, Width across Flats	*N*, Diameter of Hole	*P*, Length Over All	*Q*, Length of Hole	*S*, Depth of Full Thread
1	2	11	12	13	14	15	16	17	18
A	$\frac{3}{16}$, $\frac{1}{8}$	$\frac{1}{8}$	0.099	$\frac{1}{32}$	$\frac{7}{16}$	$\left\{\begin{matrix}0.257\\+0.003\\-0.000\end{matrix}\right\}$	$\frac{15}{32}$	$\frac{3}{32}$	$\frac{1}{4}$
B	$\frac{3}{8}$, $\frac{5}{16}$, $\frac{1}{4}$, $\frac{3}{16}$, $\frac{1}{8}$	$\frac{1}{8}$	0.196	$\frac{3}{64}$	$\frac{11}{16}$	$\left\{\begin{matrix}0.4375\\+0.003\\-0.000\end{matrix}\right\}$	$\frac{5}{8}$	$\frac{1}{8}$	$\frac{5}{16}$
C	$\frac{1}{2}$, $\frac{3}{8}$, $\frac{5}{16}$, $\frac{1}{4}$	$\frac{3}{16}$	0.280	$\frac{1}{32}$	$1\frac{1}{8}$	$\left\{\begin{matrix}0.5937\\+0.006\\-0.003\end{matrix}\right\}$	1	$\frac{5}{32}$	$\frac{11}{16}$
D	$\frac{3}{4}$, $\frac{5}{8}$, $\frac{1}{2}$, $\frac{3}{8}$	$\frac{3}{16}$	0.438	$\frac{3}{64}$	$1\frac{1}{2}$	$\left\{\begin{matrix}0.9062\\+0.006\\-0.002\end{matrix}\right\}$	$1\frac{11}{32}$	$\frac{7}{32}$	$\frac{15}{16}$

Standard Dimensions.—1. Screw threads corresponding to Class 3 of the American National fine-thread series are specified. *Right-hand threads are specified for oxygen and left-hand threads for fuel gas.*

2. Angle and outside diameter of internal seat.
3. Radius and distance of radius center of external seat from shank shoulder.
4. Diameter of shank shoulder.
5. Diameter of hole in nut.
6. Large diameter of hose shank.
7. Fuel gas nuts to be designated by annular groove around nuts, cutting corners.

Optional Features.—1. Material of strength equal to or greater than that of free-turning high brass.

2. Diameter of hole through external fitting and gland.
3. Form of end of shank, except seating section as dimensioned.
4. Length of hose shank.
5. Type and number of serrations on hose shank.
6. A second shoulder equal to the large diameter of the largest shank to extend through the hole in the nut for appearance, to be used or omitted for smaller diameter shanks.
7. Length and location of hexagon wrench section on nut.

AMERICAN NATIONAL ROLLED THREADS FOR SCREW SHELLS OF ELECTRIC SOCKETS AND LAMP BASES

The specifications given here for American National rolled threads for screw shells of electric sockets and lamp bases, with the exception of the more recently adopted intermediate size, were originally published in *Bulletin* 1474 of the American Society of Mechanical Engineers entitled Rolled Threads for Screw Shells of Electric Sockets and Lamp Bases, which was a report of the A.S.M.E. Committee on Standardization of Special Threads for Fixtures and Fittings.

TABLE 8.—AMERICAN NATIONAL ROLLED THREADS FOR LAMP-BASE SCREW SHELLS
(Dimensions in Inches)

Size	Threads per Inch	Pitch	Depth of Thread	Radius	Major Diameter		Minor Diameter	
					Max.	Min.	Max.	Min.
1	2	3	4	5	6	7	8	9
Miniature...	14	0.07143	0.020	0.0210	0.375	0.370	0.335	0.330
Candelabra..	10	0.10000	0.025	0.0312	0.465	0.460	0.415	0.410
Intermediate.	9	0.11111	0.027	0.0353	0.651	0.645	0.597	0.591
Medium.....	7	0.14286	0.033	0.0470	1.037	1.031	0.971	0.965
Mogul.......	4	0.25000	0.050	0.0906	1.555	1.545	1.455	1.455

Form of Thread.—The thread form is composed of two circular segments tangent to each other and of equal radii, as shown in Fig. 5.

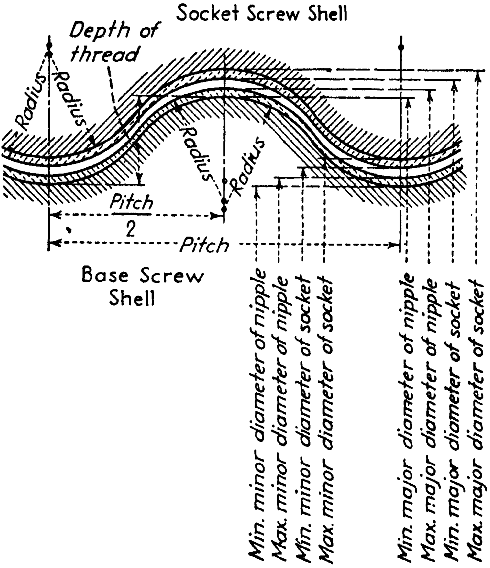

Socket Screw Shell
Depth of thread
Radius
Radius
Radius
Radius
Pitch/2
Pitch
Base Screw Shell
Min. minor diameter of nipple
Max. minor diameter of nipple
Min. minor diameter of socket
Max. minor diameter of socket
Min. major diameter of nipple
Max. major diameter of nipple
Min. major diameter of socket
Max. major diameter of socket

FIG. 5.—Thread for electric sockets.

Thread Series.—The sizes for which standard dimensions and tolerances have been adopted are designated as follows: "Miniature, candelabra, intermediate, medium, and mogul."

The threads per inch, radii of thread form, and diameter limits for these sizes of lamp-base screw shells, which are used on lamp bases, fuse plugs, attachment plugs, and similar devices, are given in Table 8.

The correspondihg dimensions and limits for socket screw shells, which are used in electric sockets, receptacles, and similar devices, are given in Table 9.

THE AERO SCREW-THREAD SYSTEM

The Aero screw thread has been developed to meet problems of securing threaded parts in aluminum and magnesium to withstand the stresses imposed by studs and bolts in aircraft engines and similar installations without failure of the softer metals. The system uses a closely wound bronze or steel coil spring insert that screws in the soft metal and receives the steel stud or bolt.

TABLE 9.—AMERICAN NATIONAL ROLLED THREADS FOR SOCKET SCREW SHELLS
(Dimensions in Inches)

Size	Threads per Inch	Pitch	Depth of Thread	Radius	Major Diameter		Minor Diameter	
					Max.	Min.	Max.	Min.
1	2	3	4	5	6	7	8	9
Miniature...	14	0.07143	0.020	0.0210	0.3835	0.3775	0.3435	0.3375
Candelabra..	10	0.10000	0.025	0.0312	0.476	0.470	0.426	0.420
Intermediate.	9	0.11111	0.027	0.0353	0.664	0.657	0.610	0.603
Medium.....	7	0.14286	0.033	0.0470	1.053	1.045	0.987	0.979
Mogul.......	4	0.25000	0.050	0.0906	1.577	1.565	1.477	1.465

It involves the use of a special tap for threading the soft metal to receive the insert and a special form of thread on the bolt or stud. The forms of these threads are shown in Figs. 6 and 7. The thread that receives the insert approximates the standard American form. Details of the tapped holes and the bolts are given in Table 10. The term V.A.T. refers to "V Aero-Thread."

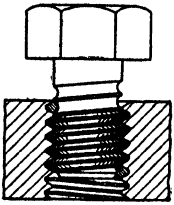


FIG. 6.—Aero screw thread and capscrew.

The first section of Table 10 refers to the bolt or stud, which has a special rounded form of thread. The second section gives dimensions of the holes tapped in the soft metal and the last section gives dimensions of the tapped hole with the insert in place. This gives the number of the insert to be used and the root diameter of the thread formed by the insert. It will be noted that the root diameter of the insert is somewhat larger than the root diameter of the standard American nut, because of the difference in thread form.

Tables 11 to 13 explain themselves.

Details of the thread in the soft metal of the insert and the thread form of the bolt, are shown in Fig. 4. The data on the different dimensions are also given.

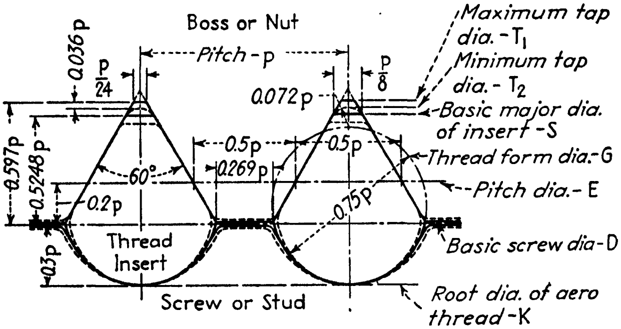


FIG. 7.—Form of Aero screw thread.

DESCRIPTION	SYMBOL
Designation for external screw form used on screw, stud, or bolt, and for internal screw form produced by insert assembled in tapped hole. Aero-Thread size is specified by nominal screw size *D* and by number of threads per inch *n*.	Aero-Thread
Designation of tapped hole V thread into which Aero-Thread insert is assembled. V.A.T. thread size is specified by screw size *D* and threads per inch *n* of screw used in insert assembled in tapped hole.	V.A.T.
Nominal screw size: major diameter of screw and minor diameter of tapped hole	*D*
Pitch diameter of tapped hole	*E*
(1) $E = D + 0.4p$	
Root diameter of screw and root diameter of insert assembled in tapped hole (minor diameter of Aero-Thread)	*K*
(2) $K = D - 0.6p = E - p$	
Major diameter of insert assembled in tapped hole	*S*
(3) $S = D + 1.0495p$	
Major diameter of tap	*T*
(4) I_1 maximum $\left(\text{flat at tip} = \frac{p}{24}\right)$ $I_2 = D + 1.194p$	
(5) T_2 minimum (radius at tip = $0.072p$) $T_2 = D + 1.122p$	
Diameter of thread form circle of Aero-Thread	*G*
(6) $G = 0.75p$	

Description	Symbol
Number of threads per inch.	n
Thread pitch.	p

$$p = \frac{1}{n} \tag{7}$$

Depth of engagement of insert in tapped hole. . . . . j

$$j = 0.525p \tag{8}$$

Depth of thread engagement, insert in screw. . . . . h

$$h = 0.3p \tag{9}$$

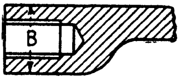
Use Class 3 fit for bolt and nut, capscrew, setscrew applications; Class 5 fit for all stud applications.

The depth of thread of the V.A.T. tapped Aero-Thread form must provide a full tapped thread depth within the limits to be specified. The Aero-Thread V.A.T. finishing tap and single-operation taps are designed to guide on the minor diameter to ensure its concentricity with the pitch diameter of the tapped thread.

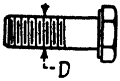
Recommended Practice for Tapping.—In soft metals drill 0.000 to 0.015 inch undersize, in which case the minimum diameter of tap will machine the minor tapped thread diameter concentric with the pitch diameter of the tapped thread. In hard cutting or abrasive materials, it is recommended that the drilled hole be reamed 0.002 to 0.006 inch oversize, in which case the tap will guide on its minor thread diameter.

Recommended Proportions of Aero-Thread Assembly.—The boss diameter B is in general the same as in the other screw systems, the relative dimensions depending on physical properties of the boss and noting screw materials as follows:

1. Tapped hole



2. Screw



Boss Material	Screw Material	Ratio of Boss B to Screw Diameter D
Steel forgings or castings.	Alloy steel	1.6 to 2.0
Aluminum alloy forgings.	Alloy steel	2.0 to 2.5
Aluminum alloy castings.	Alloy steel	2.3 to 3.0
Magnesium alloy castings.	Alloy steel	2.5 to 3.5
Aluminum alloy forgings.	Aluminum alloy	1.6 to 2.0
Aluminum alloy castings.	Aluminum alloy	1.8 to 2.4
Magnesium alloy castings.	Aluminum alloy	2.0 to 2.6

It is good practice to have a thread length *L* sufficient to ensure that under excessive loading the screw will break at the root of the screw before the thread is stripped from the boss. The following are recommended thread engagement lengths in the boss for general screw and stud applications:

MATERIAL	LENGTH OF THREAD ENGAGEMENT *L* IN TERMS OF SCREW DIAMETER *D*
Steel studs and screws in steel castings and forgings	1.5*D*
Aluminum alloy screws in aluminum or magnesium alloy bosses	1.5*D*
Steel screw or stud in light alloy materials—this standard generally used	2*D*
Steel screws or studs in light alloy castings when the screw is highly stressed and the boss material is expected to be weakened by high operating temperatures, sponginess, or material imperfections	2.5*D* or 3*D*

TABLE 10.—AERO-THREAD STANDARD SERIES CLASS 3 MEDIUM FIT (Dimensions in Inches)

Size	Threads per Inch	Aero-Thread Screw					
		Major Diameter		Root Diameter		Thread Form	
		Basic	Tolerance	Max.	Min.	Max.	Min.
$\frac{3}{16}$	24	0.1875	+0.000 −0.003	0.1625	0.1607	0.0336	0.0313
$\frac{1}{4}$	20	0.2500	+0.000 −0.004	0.2200	0.2180	0.0400	0.0375
$\frac{5}{16}$	18	0.3125	+0.000 −0.004	0.2792	0.2769	0.0445	0.0417
$\frac{3}{8}$	16	0.3750	+0.000 −0.005	0.3375	0.3351	0.0499	0.0469
$\frac{7}{16}$	14	0.4375	+0.000 −0.005	0.3946	0.3919	0.0570	0.0536
$\frac{1}{2}$	12	0.5000	+0.000 −0.006	0.4500	0.4470	0.0665	0.0624
	12	0.5625	+0.000 −0.006	0.5125	0.5095	0.0665	0.0625
$\frac{5}{8}$	10	0.6250	+0.000 −0.006	0.5650	0.5618	0.0794	0.0750
$\frac{11}{16}$	10	0.6875	+0.000 −0.006	0.6275	0.6243	0.0794	0.0750
$\frac{3}{4}$	9	0.7500	+0.000 −0.006	0.6833	0.6796	0.0881	0.0833

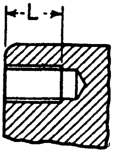
TABLE 10.—AERO-THREAD STANDARD SERIES CLASS 3 MEDIUM FIT.—*Continued*
(Dimensions in Inches)

Size	Threads per Inch	V.A.T. Tapped Hole						
		Major Diameter		Pitch Diameter		Minor Diameter		Tap Drill Size
		Max.	Min.	Max.	Min.	Max.	Min.	
3/16	24	0.2373	0.2343	0.2066	0.2042	0.1917	0.1875	No. 11
1/4	20	0.3098	0.3062	0.2726	0.2700	0.2550	0.2500	1/4
5/16	18	0.3789	0.3749	0.3377	0.3347	0.3181	0.3125	5/16
3/8	16	0.4496	0.4452	0.4032	0.4000	0.3813	0.3750	3/8
7/16	14	0.5228	0.5177	0.4697	0.4661	0.4446	0.4375	7/16
1/2	12	0.5996	0.5936	0.5373	0.5333	0.5083	0.5000	1/2
9/16	12	0.6621	0.6561	0.5998	0.5958	0.5708	0.5625	9/16
5/8	10	0.7444	0.7372	0.6695	0.6650	0.6350	0.6250	5/8
11/16	10	0.8069	0.7997	0.7320	0.7275	0.6975	0.6875	11/16
3/4	9	0.8826	0.8746	0.7993	0.7944	0.7611	0.7500	3/4

Size	Threads per Inch	V.A.T. Tapped Hole with Assembled Insert				
		Major Diameter		Root Diameter		Insert Number*
		Basic	Tolerance	Max.	Min.	
3/16	24	0.1875	+0.0042 −0.0000	0.1649	0.1625	220-30
1/4	20	0.2500	+0.0050 −0.0000	0.2226	0.2200	220-40
5/16	18	0.3125	+0.0056 −0.0000	0.2822	0.2792	220-50
3/8	16	0.3750	+0.0063 −0.0000	0.3407	0.3375	220-60
7/16	14	0.4375	+0.0071 −0.0000	0.3982	0.3946	220-70
1/2	12	0.5000	+0.0083 −0.0000	0.4540	0.4500	220-80
9/16	12	0.5625	+0.0083 −0.0000	0.5165	0.5125	220-90
5/8	10	0.6250	+0.0100 −0.0000	0.5695	0.5650	220-100
11/16	10	0.6875	+0.0100 −0.0000	0.6320	0.6275	220-110
3/4	9	0.7500	+0.0111 −0.0000	0.6882	0.6833	220-120

NOTE: For larger sizes use eight-thread series (Table 12).
* See Table 12 for length of insert.

1. Tapped Hole



2. Stud

Notes

D. Basic major diameter or nominal size

B. Boss diameter

L. Thread length

TABLE 11.—AERO-THREAD STANDARD SERIES CLASS 5 STUD FIT (Dimensions in Inches)

Size	Threads per Inch	Aero-Thread Screw					
		Major Diameter		Root Diameter		Thread Form Diameter	
		Basic	Tolerance	Max.	Min.	Max.	Min.
3/16	24	0.1875	+0.000 −0.003	0.1677	0.1665	0.0336	0.0313
1/4	20	0.2500	+0.000 −0.004	0.2255	0.2242	0.0400	0.0375
5/16	18	0.3125	+0.000 −0.004	0.2855	0.2840	0.0445	0.0417
3/8	16	0.3750	+0.000 −0.005	0.3445	0.3429	0.0499	0.0469
7/16	14	0.4375	+0.000 −0.005	0.4024	0.4006	0.0570	0.0536
1/2	12	0.5000	+0.000 −0.006	0.4584	0.4564	0.0665	0.0625
9/16	12	0.5625	+0.000 −0.006	0.5211	0.5191	0.0665	0.0625
5/8	10	0.6250	+0.000 −0.006	0.5741	0.5719	0.0794	0.0750
3/4	9	0.7500	+0.000 −0.006	0.6926	0.6902	0.0881	0.0833

Size	Threads per Inch	V.A.T. Tapped Hole						
		Major Diameter		Pitch Diameter		Minor Diameter		Tap Drill Size
		Max.	Min.	Max.	Min.	Max.	Min.	
3/16	24	0.2373	0.2343	0.2066	0.2042	0.1917	0.1875	No. 11
1/4	20	0.3098	0.3062	0.2726	0.2700	0.2550	0.2500	1/4
5/16	18	0.3789	0.3749	0.3377	0.3347	0.3181	0.3125	5/16
3/8	16	0.4496	0.4452	0.4032	0.4000	0.3813	0.3750	3/8
7/16	14	0.5228	0.5177	0.4697	0.4661	0.4446	0.4375	7/16
1/2	12	0.5996	0.5936	0.5373	0.5333	0.5083	0.5000	1/2
9/16	12	0.6621	0.6561	0.5998	0.5958	0.5708	0.5625	9/16
5/8	10	0.7444	0.7372	0.6695	0.6650	0.6350	0.6250	5/8
3/4	9	0.8826	0.8746	0.7993	0.7944	0.7611	0.7500	3/4

TABLE 11.—AERO-THREAD STANDARD SERIES CLASS 5 STUD FIT.—*Continued*

Size	Threads per Inch	V.A.T. Tapped Hole with Assembled Insert				
		Major Diameter		Root Diameter		Insert Number
		Basic	Tolerance	Max.	Min.	Length See Note
3/16	24	0.1875	+0.0042 −0.0000	0.1649	0.1625	220-30
1/4	20	0.2500	+0.0050 −0.0000	0.2226	0.2200	220-40
5/16	18	0.3125	+0.0056 −0.0000	0.2822	0.2792	220-50
3/8	16	0.3750	+0.0063 −0.0000	0.3407	0.3375	220-60
7/16	14	0.4375	+0.0071 −0.0000	0.3982	0.3946	220-70
1/2	12	0.5000	+0.0083 −0.0000	0.4540	0.4500	220-80
9/16	12	0.5625	+0.0083 −0.0000	0.5165	0.5125	220-90
5/8	10	0.6250	+0.0100 −0.0000	0.5695	0.5650	220-100
3/4	9	0.7500	+0.0111 −0.0000	0.6882	0.6833	220-120

NOTE: See Table 12 for length of insert.
First three threads of stud to conform to Table 10.

TABLE 12.—AERO-THREAD INSERT STANDARD SIZES
To Designate Insert Material Use Symbol *B* for Phosphor Bronze or *C* for Stainless Steel after Insert Number
(Dimensions in Inches)

Size	Threads per Inch	Insert Number	Free Diameter	Assembled Length of Insert *L*				Overall Depth of Hole
				1.5*D*	2*D*	2.5*D*	3*D*	
3/16	24	220-30	0.250	9/32	3/8	15/32	9/16	1/8 + *L*
1/4	20	220-40	0.330	3/8	1/2	5/8	3/4	5/32 + *L*
5/16	18	220-50	0.405	15/32	5/8	25/32	15/16	3/16 + *L*
3/8	16	220-60	0.485	9/16	3/4	15/16	1 1/8	3/16 + *L*
7/16	14	220-70	0.570	21/32	7/8	1 3/32	1 5/16	7/32 + *L*
1/2	12	220-80	0.645	3/4	1	1 1/4	1 1/2	1/4 + *L*
9/16	12	220-90	0.730	27/32	1 1/8	1 13/32	1 11/16	1/4 + *L*
5/8	10	220-100	0.810	1 1/16	1 1/4	1 9/16	1 7/8	5/16 + *L*
11/16	10	220-110	0.900	1 1/32	1 3/8	1 23/32	2 1/16	5/16 + *L*
3/4	9	220-120	0.990	1 1/8	1 1/2	1 7/8	2 1/4	11/32 + *L*

NOTE: Depth of tapped hole is generally 1/32 to 1/16 longer than assembled length of insert.

TABLE 13.—AERO-THREAD EIGHT THREAD SERIES CLASS 3 MEDIUM FIT
(Dimensions in Inches)

Size	Threads per Inch	Aero-Thread Screw					
		Major Diameter		Root Diameter		Thread Form Diameter	
		Basic	Tolerance	Max.	Min.	Max.	Min.
7/8	8	0.8750	+0.000 −0.006	0.8000	0.7958	0.0990	0.0938
1	8	1.0000	+0.000 −0.006	0.9250	0.9208	0.0990	0.0938
1 1/8	8	1.1250	+0.000 −0.007	1.0500	1.0457	0.0990	0.0938
1 1/4	8	1.2500	+0.000 −0.007	1.1750	1.1704	0.0990	0.0938
1 3/8	8	1.3750	+0.000 −0.007	1.3000	1.2953	0.0990	0.0938
1 1/2	8	1.5000	+0.000 −0.007	1.4250	1.4201	0.0990	0.0938
1 5/8	8	1.6250	+0.000 −0.007	1.5500	1.5449	0.0990	0.0938
1 3/4	8	1.7500	+0.000 −0.007	1.6750	1.6698	0.0990	0.0938
1 7/8	8	1.8750	+0.000 −0.008	1.8000	1.7945	0.0990	0.0938
2	8	2.000	+0.000 −0.007	1.9250	1.9194	0.0990	0.0938
2 1/8	8	2.125	+0.000 −0.007	2.0500	2.0442	0.0990	0.0938
2 1/4	8	2.250	+0.000 −0.008	2.1750	2.1689	0.0990	0.0938
2 1/2	8	2.500	+0.000 −0.008	2.4250	2.4185	0.0990	0.0938
2 3/4	8	2.750	+0.000 −0.008	2.6750	2.6681	0.0990	0.0938
3	8	3.000	+0.000 −0.008	2.9250	2.9180	0.0990	0.0938
3 1/4	8	3.250	+0.000 −0.008	3.1750	3.1680	0.0990	0.0938
3 1/2	8	3.500	+0.000 −0.008	3.4250	3.4179	0.0990	0.0938
3 3/4	8	3.750	+0.000 −0.008	3.6750	3.6679	0.0990	0.0938
4	8	4.000	+0.000 −0.008	3.9250	3.9178	0.0990	0.0938
4 1/4	8	4.250	+0.000 −0.009	4.1750	4.1677	0.0990	0.0938
4 1/2	8	4.500	+0.000 −0.009	4.4250	4.4177	0.0990	0.0938
4 3/4	8	4.750	+0.000 −0.009	4.6750	4.6676	0.0990	0.0938
5	8	5.000	+0.009 −0.009	4.9250	4.9176	0.0990	0.0938
5 1/4	8	5.250	+0.000 −0.009	5.1750	5.1675	0.0990	0.0938
5 1/2	8	5.500	+0.009 −0.009	5.4250	5.4174	0.0990	0.0938
5 3/4	8	5.750	+0.000 −0.009	5.6750	5.6673	0.0990	0.0938
6	8	6.000	+0.000 −0.009	5.9250	5.9173	0.0990	0.0938

TABLE 13.—AERO-THREAD EIGHT THREAD SERIES CLASS 3 MEDIUM FIT.—*Continued*

Size	Threads per Inch	V.A.T. Tapped Hole						
		Major Diameter		Pitch Diameter		Minor Diameter		Tap Drill Size
		Max.	Min.	Max.	Min.	Max.	Min.	
⅞	8	1.0150	1.0000	0.9242	0.9188	0.8875	0.8750	⅞
1	8	1.1400	1.1250	1.0493	1.0438	1.0125	1.0000	1
1⅛	8	1.2650	1.2500	1.1746	1.1688	1.1375	1.1250	1⅛
1¼	8	1.3900	1.3750	1.2999	1.2938	1.2625	1.2500	1¼
1⅜	8	1.5150	1.5000	1.4251	1.4188	1.3875	1.3750	1⅜
1½	8	1.6400	1.6250	1.5503	1.5438	1.5125	1.5000	1½
1⅝	8	1.7650	1.7500	1.6756	1.6688	1.6375	1.6250	1⅝
1¾	8	1.8900	1.8750	1.8008	1.7938	1.7625	1.7500	1¾
1⅞	8	2.0150	2.0000	1.9261	1.9188	1.8875	1.8750	1⅞
2	8	2.140	2.125	2.0513	2.0438	2.0125	2.0000	2
2⅛	8	2.265	2.250	2.1765	2.1688	2.1375	2.1250	2⅛
2¼	8	2.390	2.375	2.3020	2.2938	2.2625	2.2500	2¼
2½	8	2.640	2.625	2.5525	2.5438	2.5125	2.5000	2½
2¾	8	2.890	2.875	2.8030	2.7938	2.7625	2.7500	2¾
3	8	3.140	3.125	3.0531	3.0438	3.0125	3.0000	3
3¼	8	3.390	3.375	3.3031	3.2938	3.2625	3.2500	3¼
3½	8	3.640	3.625	3.5532	3.5438	3.5125	3.5000	3½
3¾	8	3.890	3.875	3.8033	3.7938	3.7625	3.7500	3¾
4	8	4.140	4.125	4.0534	4.0438	4.0125	4.0000	4
4¼	8	4.390	4.375	4.3035	4.2938	4.2625	4.2500	4¼
4½	8	4.640	4.625	4.5536	4.5438	4.5125	4.5000	4½
4¾	8	4.890	4.875	4.8037	4.7938	4.7625	4.7500	4¾
5	8	5.140	5.125	5.0537	5.0438	5.0125	5.0000	5
5¼	8	5.390	5.375	5.3038	5.2938	5.2625	5.2500	5¼
5½	8	5.640	5.625	5.5539	5.5438	5.5125	5.5000	5½
5¾	8	5.890	5.875	5.8040	5.7938	5.7625	5.7500	5¾
6	8	6.140	6.125	6.0540	6.0438	6.0125	6.0000	6

TABLE 13.—AERO-THREAD EIGHT THREAD SERIES CLASS 3 MEDIUM FIT.—*Continued*

Size	Threads per Inch	V.A.T. Tapped Hole with Assembled Insert				
		Major Diameter		Root Diameter		Insert Number*
		Basic	Tolerance	Max.	Min.	
⅞	8	0.8750	+0.0125 −0.0000	0.8054	0.8000	220-140
1	8	1.0000	+0.0125 −0.0000	0.9305	0.9250	220-160
1⅛	8	1.1250	+0.0125 −0.0000	1.0558	1.0500	220-180
1¼	8	1.2500	+0.0125 −0.0000	1.1811	1.1750	220-200
1⅜	8	1.3750	+0.0125 −0.0000	1.3063	1.3000	220-220
1½	8	1.5000	+0.0125 −0.0000	1.4315	1.4250	220-240
1⅝	8	1.6250	+0.0125 −0.0000	1.5568	1.5500	220-260
1¾	8	1.7500	+0.0125 −0.0000	1.6820	1.6750	220-280
1⅞	8	1.8750	+0.0125 −0 0000	1.8073	1.8000	220-300
2	8	2.000	+0.0125 −0.0000	1.9325	1.9250	220-320
2⅛	8	2.125	+0.0125 −0.0000	2.0577	2.0500	220-340
2¼	8	2.250	+0.0125 −0.0000	2.1832	2.1750	220-360
2½	8	2.500	+0.0125 −0.0000	2.4337	2.4250	220-400
2¾	8	2.750	+0.0125 −0.0000	2.6842	2.6750	220-440
3	8	3.000	+0.0125 −0.0000	2.9343	2.9250	220-480
3¼	8	3.250	+0.0125 −0.0000	3.1843	3.1750	220-520
3½	8	3.500	+0.0125 −0.0000	3.4344	3.4250	220-560
3¾	8	3.750	+0.0125 −0.0000	3.6845	3.6750	220-600
4	8	4.000	+0.0125 −0.0000	3.9346	3.9250	220-640
4¼	8	4.250	+0.0125 −0.0000	4.1847	4.1750	220-680
4½	8	4.500	+0.0125 −0.0000	4.4348	4.4250	220-720
4¾	8	4.750	+0.0125 −0.0000	4.6849	4.6750	220-760
5	8	5.000	+0.0125 −0.0000	4.9349	4.9250	220-800
5¼	8	5.250	+0.0125 +0.0000	5.1850	5.1750	220-840
5½	8	5.500	+0.0125 −0.0000	5.4351	5.4250	220-880
5¾	8	5.750	+0 0125 −0.0000	5.6852	5.6750	220-920
6	8	6.000	+0.0125 −0.0000	5.9352	5 9250	220-960

*** Length of insert: 1½, 2, 2½, and 3 basic diameter.**

SECTION III

DRILLING

DEEP-HOLE DRILLING

The drilling of rifle barrels of various diameters for guns used in the war has given wide experience in deep-hole drilling. One such drill is shown in Fig. 1. This had cemented carbide drill tips that were ground to the shape shown in the detail sketches. As will be seen, this is a single-lip drill, as is common in work of this kind. It is the first drill for a 20-mm. gun, the drill being 19 mm., or

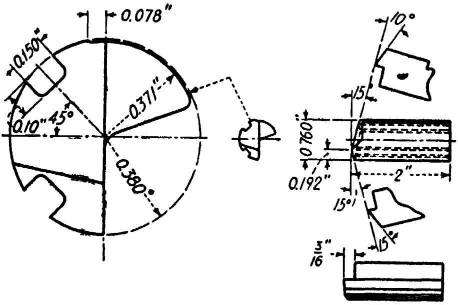
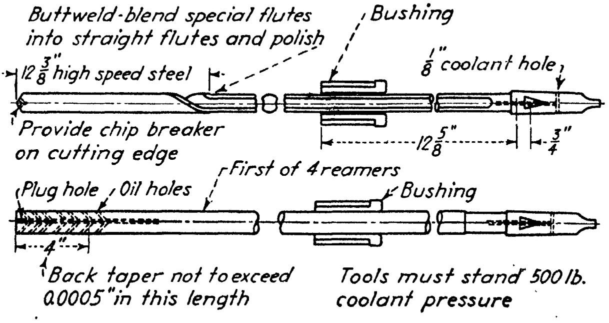


FIG. 1.—Deep-hole drill.



Buttweld-blend special flutes into straight flutes and polish
Bushing
12 3/8" high speed steel
1/8" coolant hole
Provide chip breaker on cutting edge
12 5/8"
3/4"
First of 4 reamers
Plug hole
Oil holes
Bushing
4"
Back taper not to exceed 0.0005" in this length
Tools must stand 500 lb. coolant pressure

FIG. 2.—Drill for larger hole.

0.760 inch. The drill is guided through a suitable bushing and the chips are washed out through the V groove by coolant at 500 pounds pressure.

The drilling speed was 1,040 r.p.m. or about 50 feet per minute. The feed was 0.001 inch per revolution. The barrel was after-reamed in three passes to 19.96 mm. and finally honed to 20 mm. The drilling and reaming coolant was 80 per cent sulphurized oil and 20 per cent light mineral oil.

Another type of drill for a larger hole, 1.81 inches, is seen in Fig. 2. This was a flat drill of high-speed steel for 12⅝ inches, as shown, butt-welded to a special section of steel rod, as shown. The flutes of the shank were polished to make it easier for the chips to be forced out with the same pressure as before, 500 pounds.

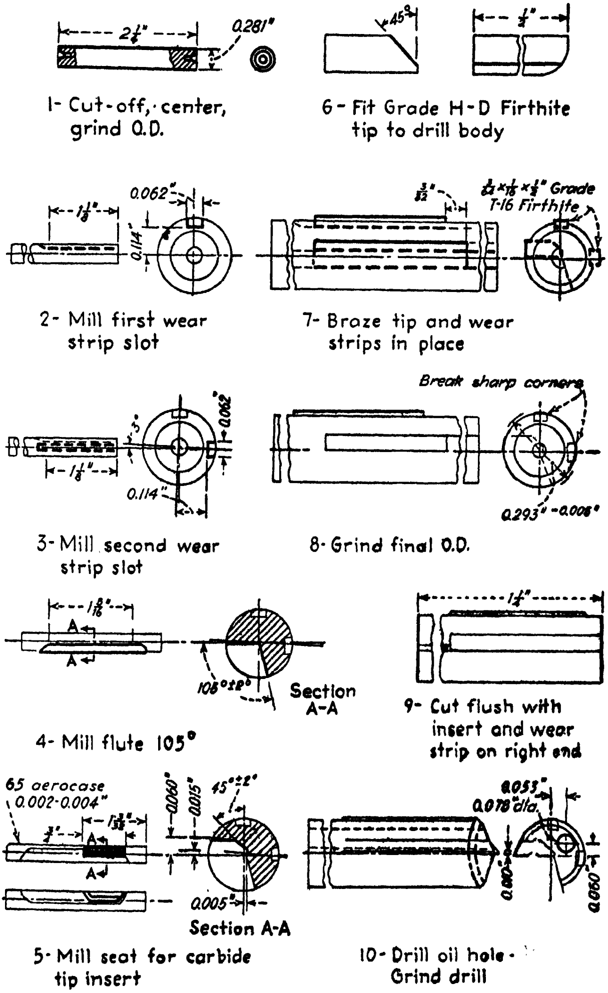
DRILLING RIFLE BARRELS WITH CARBIDE TOOLS

Gun drills with carbide tips and carbide wear plates around the periphery of the drill will give exceptionally high production rates because of fast permissible feeds and long life between grinds. Such drills, designed and manufactured at the Poughkeepsie plant of International Business Machines, Inc., are, according to manufacturing engineer T. R. Skofteland, being used for drilling gun barrels and other gun parts made from steel up to 380 Brinell hardness and have run as long as 20 hours between grinds. Compared with high-speed steel drills, feeds have in some cases been doubled. The two carbide wear plates which back up the tip show negligible wear throughout the life of the drill, thereby maintaining its accuracy and producing smooth holes with minimum run-out.

Standard drills of 0.293, 0.300, 0.330, 0.494, 0.697, 0.733 and 0.781 inch in diameter have been made to date, using the production sequences illustrated for the 0.293-inch size, Fig. 3. A drill of entirely different design, but also employing the carbide tip and wear plates, is used for drilling a 1.150 inch air-cylinder hole in the receiver body of a 20-millimeter automatic cannon. The production sequence and design of this latter drill are shown in a second drawing, Fig. 4.

Seats for the carbide tip and wear plates are milled in the drills. Grade H-D Firthite is used for the cutting tip, while Grade T-16 Firthite is used for the wear plates. Both the tip and wear plates are brazed in the slots using Hand & Harmon's Easy-Flow No. 3 metal. The conventional gun-drill grind is used on all sizes. It is important that the cutting edges be honed to a mirror finish.

The 0.293-inch drill shown is for drilling 30 caliber rifle barrels 24 inches long. Although an average feed of 2 inches per minute is used, 2½ inches per minute has been maintained for long runs. In production, this drill has been used for 20 hours without grinding. Drilling is done in W. F. & John Barnes six-spindle vertical machines, the spindles running at 2,800 r.p.m. Each machine turns out one 30 caliber barrel every 2 to 3 minutes. Based on an average life of 20 hours between grinds, each drill is good for 70 to 75 barrels before resharpening. Comparable production has been attained with drills of other sizes.



1- Cut-off, center, grind O.D.

6- Fit Grade H-D Firthite tip to drill body

2- Mill first wear strip slot

7- Braze tip and wear strips in place

3- Mill second wear strip slot

8- Grind final O.D.

4- Mill flute 105°

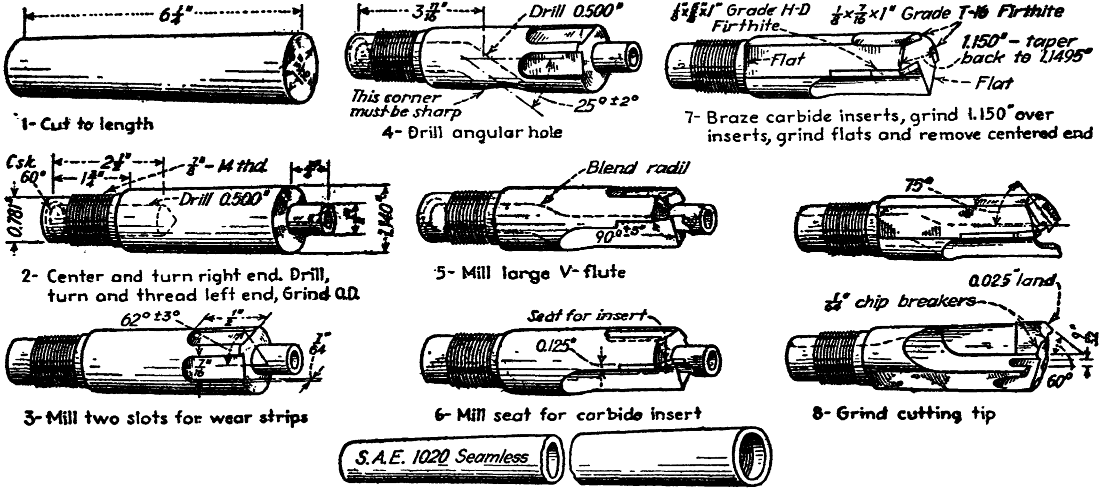
9- Cut flush with insert and wear strip on right end

5- Mill seat for carbide tip insert

10- Drill oil hole - Grind drill

OPERATIONS ON THE 0.293" GUN DRILL

FIG. 3.



1- Cut to length

4- Drill angular hole

7- Braze carbide inserts, grind 1.150" over inserts, grind flats and remove centered end

2- Center and turn right end. Drill, turn and thread left end, Grind O.D.

5- Mill large V-flute

3- Mill two slots for wear strips

6- Mill seat for carbide insert

8- Grind cutting tip

Drill extension - 1.062" dia., 68" long

OPERATIONS ON THE 1.150" GUN DRILL

FIG. 4.

The manufacturing sequence on all the drills is somewhat similar. That for the 0.594-inch drill is as follows:

1. The stock is cut-off, centered, and ground to 0.578 inch diameter.
2. Grooves for the wear plates, the chip flute, and the seat for the carbide tip are milled.
3. The wear plates and carbide tip are brazed in place.
4. The stock is ground on centers to the correct diameter over the carbide inserts, leaving the body slightly undersize, in this case, 0.578 inch. The latter eliminates the need of relief or back-off on the drill.
5. Both centered ends are cut-off and the oil hole is drilled.
6. The drill tip is butt-welded to the conventional fluted-type seamless-tube shank.
7. Finally, the drill is sharpened.

This drill, as well as the other sizes, may be made from drill rod.

Better results, however, are obtained with S.A.E. 3115 steel Aerocase hardened to a depth of 0.003 to 0.005 inch before brazing in the wear plates and tip. Case hardening minimizes the danger of picking up chips and slight tears on the soft core of the barrel when drilling. The 0.578 inch diameter drill will run up to 20 hours without sharpening and will take a feed of 1½ inches with ease.

The machine used for drilling the 1.150-inch air-cylinder hole in the receiver body of 20-millimeter automatic cannon was originally built for a two-lipped drill with the chip return through the center of the drill extension. Chips would often plug this center hole, causing the stock to run out as much as 0.030 inch in 24 inches. This condition was overcome completely by the 1.150-inch drill shown in the drawing. The double lip was replaced by a single lip tipped with carbide and backed up with two carbide wear plates. Since this drill was designed, run-out in the receiver body has been held consistently within 0.008 inch in 24 inches. Chip breakers, ground as steps on the cutting edge, split the chips while drilling and reduce the possibility of the plugging. The success of this drill is partly due, of course, to the rigidity of the round extension tube compared with the conventional fluted seamless tube used on small drills. Another asset is the ease of removing the drill by simply unscrewing it from the extension tube.

The 1.150-inch drill is used in a No. 420 W. F. & John Barnes horizontal drilling machine while running at a speed of 600 r.p.m. The speed should be higher, but due to the heavy cradle used for holding the work it is not essential. At the 600 r.p.m. speed, the drill feed is ⅞ to 1 inch per minute, under which conditions the drill can be used for 10 hours and more without resharpening. A feed of 1½ inches per minute can be used at higher speeds. The tailstock of the machine is so constructed as to let the oil, under pressure, enter along the drill extension-which is ⅛ inch smaller in diameter than the drill. The oil flows along the two outside flats on the drill up to the point, and finally back through the flute and hole in the extension tube, carrying the chips with it.

The illustrations, Figs. 3 and 4, are self-explanatory.

Gun-Barrel Reamers and Broaches.—Wood-packed reamers for finishing the bore of cannon of various sizes are still largely used in gun shops. One of these, such as used in the Watervliet Arsenal, is shown in Fig. 5. The dimensions of the various parts are given for four sizes, 37 mm., 75 mm., 3 in., and 105 mm.

The wood-packed tool is a cutting head followed by two semi-round wood inserts which support the bar in the bore. These inserts are made of hard maple which is kept under vacuum for 24 hours to remove all the moisture. It is then soaked in an impregnating oil for 24 hours. The ends are waxed to keep the wood from checking.

When ready to use, the wood is turned 0.005 inch larger than the reamer size to ensure a rigid support for the bar. High-speed blades are used for the roughing ream and carbon steel for the finishing cut. The gun tube is first counterbored for a short distance to ensure the reamer's being started straight. As the wood packing must be replaced after each bore, this makes an expensive method both in material and in time.

More modern practice is to use babbitt as a packing instead of wood, and carbide-tipped cutters instead of high speed and carbon. This has two advantages: the carbide cutters maintain their size for the whole length of the bore and so eliminate all chance of a taper hole, and the babbitt packing can be used for six or eight bores before they need to be replaced.

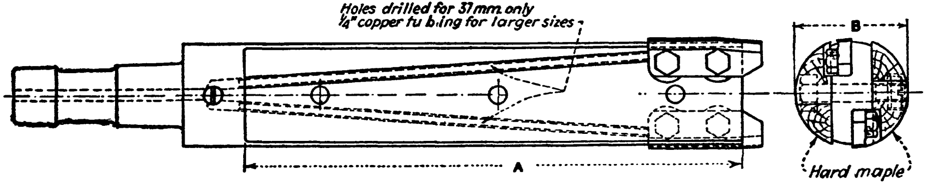
The babbitt packings are turned with about 0.001-inch clearance instead of being oversize, as with the wood-packed reamers. Details of the babbitt-packed reamers are seen in Figs. 6 and 7.

Portable-Boring-Bar Feeds and Speeds.—The Van Norman Machine Tool Co. recommends the following feeds and speeds for their cylinder-boring bars.

TABLE 1.—BORING-BAR FEEDS AND SPEEDS

Diameter of Hole in Inches	Depth of Hole in Inches	R.P.M. of Bar	Feed in Inches per Minute
1.9 to 3.8	10	355	$1\frac{5}{8}$
2.2 to 4.25	10	344	$1\frac{3}{4}$
2.6 to 5.25	14	285	$1\frac{3}{4}$
Two-speed bars:			
2.6 to 5.34	14	High 375	$2\frac{1}{2}$
		Low 220	$1\frac{1}{2}$
3.49 to 7.5	18	High 234	$1\frac{3}{16}$
		Low 162	$\frac{27}{32}$
4.35 to 9	30	High 169	$\frac{29}{32}$
		Low 117	$\frac{5}{8}$

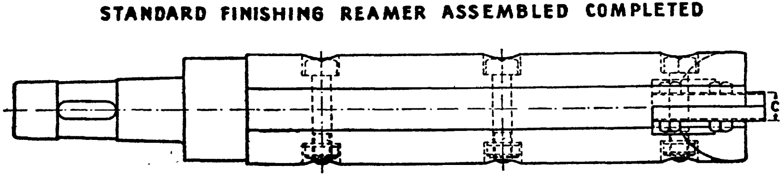
Gun-Barrel Broaches.—Broaches are now used to cut the rifling grooves in gun barrels instead of the old, slow method of


Holes drilled for 37mm only
¼" copper tubing for larger sizes
A
B
Hard maple

DIMENSIONS FOR REAMER BODIES

GUN	A	B	C	N	SHANK	A1	A2	A3	A4	A5	A6	A7
37 M/M	7.0	1.25	0.54	¼"– 20 thds. per in.	No. 9 B&S	2.0	0.60	0.187	2.0	0.187	0.30	0.56
75 M/M	13.25	2.80	1.125	⅜"– 16 thds. per in.	No. 0	3.0	1.10	0.375	2.62	0.437	0.375	0.62
3"	13.25	2.80	1.125	⅜"– 16 thds. per in.	No. 0	3.0	1.10	0.375	2.62	0.437	0.375	0.62
105 M/M	17.0	3.90	1.50	7/16 14 thds. per in.	No. 1	3.87	1.25	0.375	3.25	0.50	0.50	075

STANDARD FINISHING REAMER ASSEMBLED COMPLETED



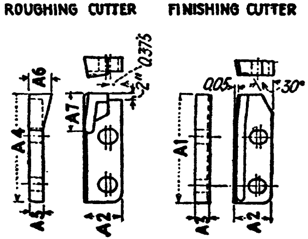


FIG. 5.—Wood-packed reamer.

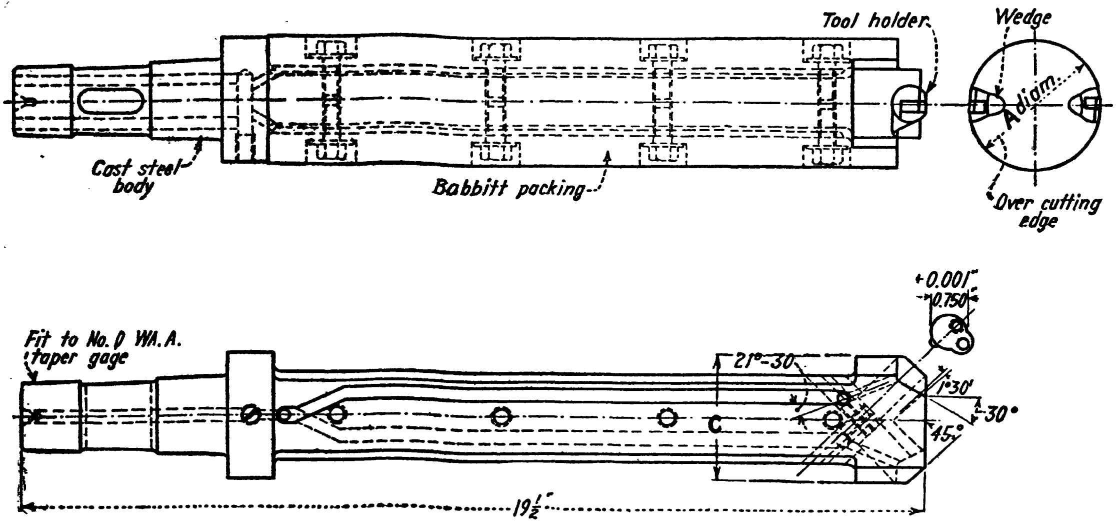


FIG. 6.—The new babbitt-packed reamers use carbide cutters. A set of three gets the 75-mm. tube ready for the honing operation.

REAMER #	A	B	C	OPER.
1	2.70	2.699	2.65	1st roughing
2	2.850	2.849	2.800	2nd roughing
3	$2.945^{+0.0005}$	2.944	2.895	Finishing

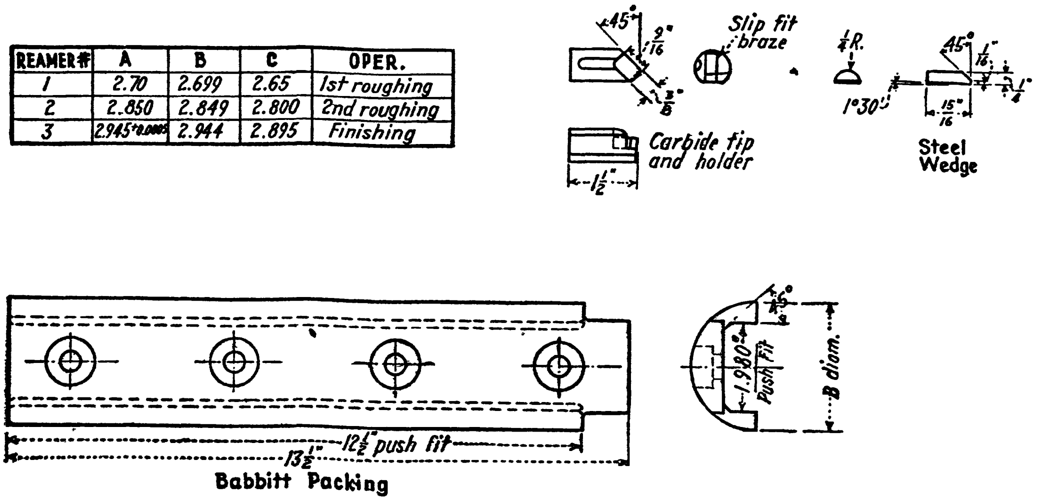
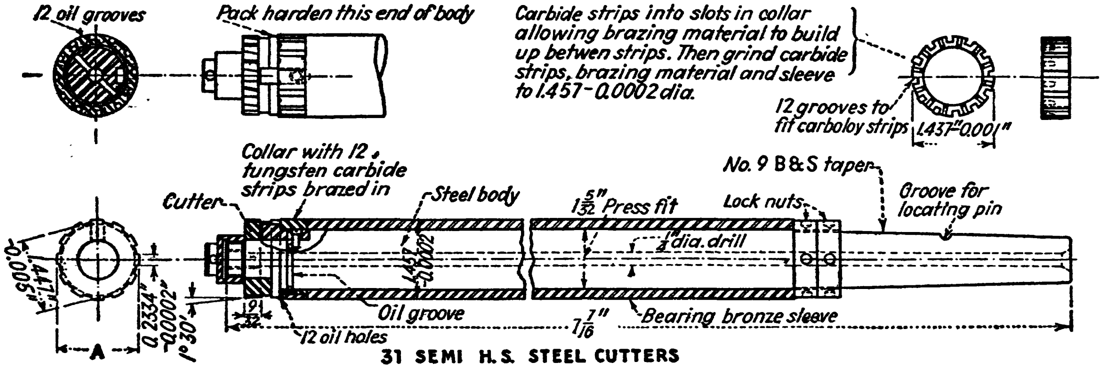


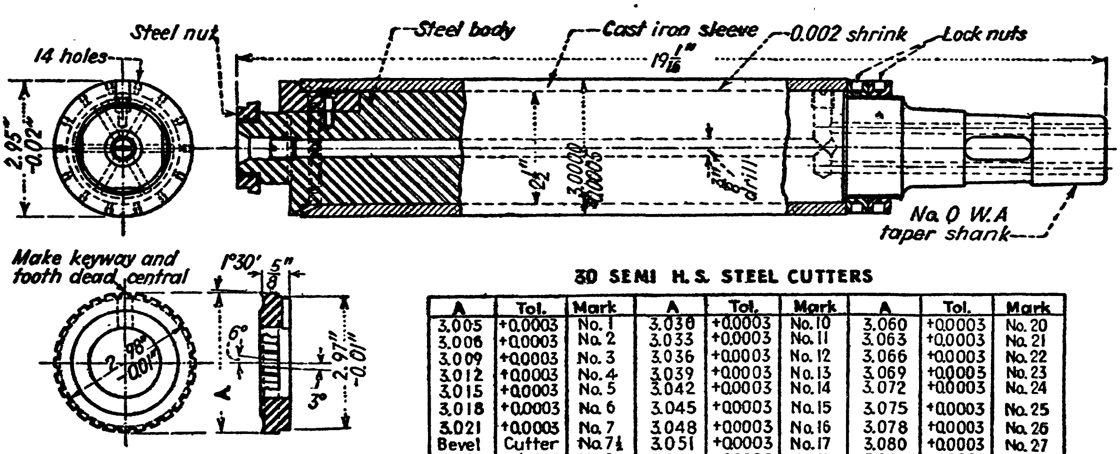
FIG. 7.—Details of babbitt packing and steel wedge.


Carbide strips into slots in collar allowing brazing material to build up betwen strips. Then grind carbide strips, brazing material and sleeve to 1.457-0.0002 dia.

31 SEMI H.S. STEEL CUTTERS

A	Tol.	Mark	A	Tol.	Mark	A	Tol.	Mark	A	Ton.	Mark
1.4590	+0.0003	No. 1	1.4710	+0.0003	No. 9	1.4830	+0.0003	No. 17	1.4950	+0.0002	No. 25
1.4605	+0.0003	No. 2	1.4725	+0.0003	No. 10	1.4845	+0.0003	No. 18	1.4955	+0.0002	No. 26
1.4620	+0.0003	No. 3	1.4740	+0.0003	No. 11	1.4860	+0.0003	No. 19	1.4960	+0.0002	No. 27
1.4635	+0.0003	No. 4	1.4755	+0.0003	No. 12	1.4875	+0.0003	No. 20	1.4965	+0.0002	No. 28
1.4650	+0.0003	No. 5	1.4770	+0.0003	No. 13	1.4890	+0.0003	No. 21	1.4970	+0.0002	No. 29
1.4665	+0.0003	No. 6	1.4785	+0.0003	No. 14	1.4905	+0.0003	No. 22	1.4975	+0.0002	No. 30
1.4680	+0.0003	No. 7	1.4800	+0.0003	No. 15	1.4920	+0.0003	No. 23	1.4980	+0.0002	No. 31
1.4695	+0.0003	No. 8	1.4815	+0.0003	No. 16	1.4935	+0.0003	No. 24			

FIG. 8.—Broaching cutters for gun barrels.



30 SEMI H.S. STEEL CUTTERS

A	Tol.	Mark	A	Tol.	Mark	A	Tol.	Mark
3.005	+0.0003	No. 1	3.030	+0.0003	No. 10	3.060	+0.0003	No. 20
3.006	+0.0003	No. 2	3.033	+0.0003	No. 11	3.063	+0.0003	No. 21
3.009	+0.0003	No. 3	3.036	+0.0003	No. 12	3.066	+0.0003	No. 22
3.012	+0.0003	No. 4	3.039	+0.0003	No. 13	3.069	+0.0003	No. 23
3.015	+0.0003	No. 5	3.042	+0.0003	No. 14	3.072	+0.0003	No. 24
3.018	+0.0003	No. 6	3.045	+0.0003	No. 15	3.075	+0.0003	No. 25
3.021	+0.0003	No. 7	3.048	+0.0003	No. 16	3.078	+0.0003	No. 26
Bevel	Cutter	No. 7½	3.051	+0.0003	No. 17	3.080	+0.0003	No. 27
3.024	+0.0003	No. 8	3.054	+0.0003	No. 18	3.081	+0.0003	No. 28
3.027	+0.0003	No. 9	3.057	+0.0003	No. 19	3.082	+0.0003	No. 29

FIG. 9.—Broaching has also been applied to the 3-in. AA gun. The shank and broaching disks are shown.

cutting the grooves with a frail hook tool. Figures 7 and 8 give details of the broaching cutters used in cutting the rifling grooves in the 37-mm. and in the 3-inch antiaircraft gun.

The 37-mm. gun has 12 grooves 0.02 inch deep and 0.234 inch wide. The first broaches remove 0.0015 to 0.003 inch of metal, the last 0.0005 to 0.001 inch. A lubricant of 3 parts kerosene and 1 part lard oil at 70 pound pressure flushes the chips out ahead of the tool and keeps them from marring the bearing surface which guides the bar.

Diamond-Core Drill Fittings.—Diamond-core drill fittings have been standardized since 1929, the last revision of the standard being endorsed Mar. 25, 1941. This standard covers designs and tolerances with controlling dimensions for rod couplings, drill rods, core-barrel bits, reaming shells, core-barrel outer tubes and inner tubes, casing couplings, flush-coupled casings, flush-joint casings, and casing bits. Dimensions of core-barrel bits and reaming shells apply to these items as they leave the machine and *before* being set with drilling diamonds.

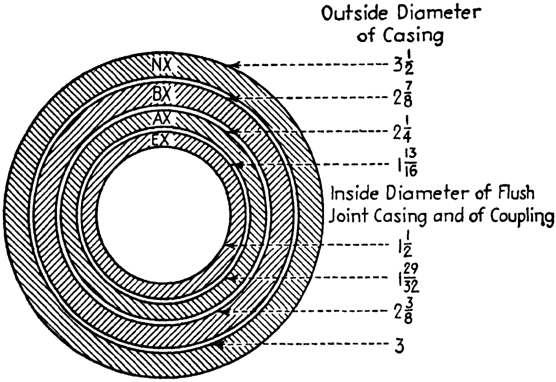


FIG. 10.—Sizes of core barrels.

It will be noted that while the threads are called "square" they have a 5-degree angle on each side which makes them much easier to cut. Figure 10 shows the relations between the four sizes listed. Table 4 shows the corresponding core barrels, core-barrel bits, reaming shells, and rod couplings.

The term "reaming shell" is now used in place of "swell coupling."

The only difference between the bevel-wall and the straight-wall bit is the large diameter of the hole, shown in *Z*, Table 5, and an extension of the *K* diameter $\frac{1}{32}$ inch beyond the thread.

TABLE 2.—NOMINAL DIMENSIONS

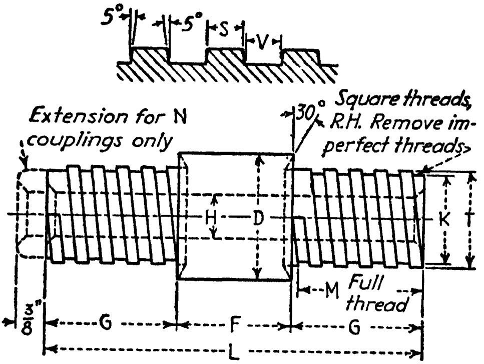
Casing, Casing Coupling, Casing Bits	Core Barrels, Core-barrel Bits, Reaming Shells	Rod, Rod Couplings	Casing		Casing Bit, O. D., in Inches	Core-Barrel Bit, O. D., in Inches	Core-Barrel Bit, I.D., in Inches	Reaming Shell, O. D., in Inches	Drill Rod, O. D., in Inches	Approx. Diameter of Hole Made by Core-barrel Bit and Shell,† Inches	Approx. Diameter of Core,‡ in Inches
			O. D., in Inches	I. D.,* in Inches							
EX	EXT	E	$1\frac{13}{16}$	$1\frac{1}{2}$	$1\frac{55}{64}$	$1\frac{27}{64}$	$\frac{15}{16}$	$1\frac{29}{64}$	$1\frac{5}{16}$	$1\frac{1}{2}$	$\frac{15}{16}$
AX	AXT	A	$2\frac{1}{4}$	$1\frac{29}{32}$	$2\frac{21}{64}$	$1\frac{53}{64}$	$1\frac{5}{16}$	$1\frac{55}{64}$	$1\frac{5}{8}$	$1\frac{7}{8}$	$1\frac{5}{16}$
BX	BX	B	$2\frac{7}{8}$	$2\frac{3}{8}$	$2\frac{61}{64}$	$2\frac{19}{64}$	$1\frac{11}{16}$	$2\frac{21}{64}$	$1\frac{29}{32}$	$2\frac{3}{8}$	$1\frac{5}{8}$
NX	NX	N	$3\frac{1}{2}$	3	$3\frac{37}{64}$	$2\frac{59}{64}$	$2\frac{3}{16}$	$2\frac{61}{64}$	$2\frac{3}{8}$	3	$2\frac{1}{8}$

* Inside diameter of flush-joint casing, and of coupling of flush-coupled casing.

† Assuming hole $\frac{1}{32}$ inch larger than reaming shell and listing diameters to nearest $\frac{1}{16}$ inch.

‡ Assuming core $\frac{1}{32}$ inch smaller than I. D. of bit and listing diameters to nearest $\frac{1}{16}$ inch.

TABLE 3.—ROD COUPLINGS


5°
5°
S
V
Extension for N couplings only
30°
Square threads, R.H. Remove imperfect threads
H
D
K
T
M
Full thread
3/8"
G
F
G
L

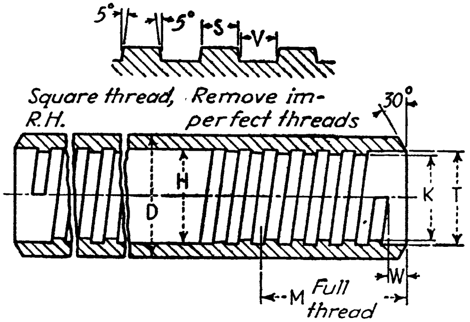
Designating Symbol	D, in Inches	F, in Inches	G, in Inches	H, in Inches	Threads per Inch	K, in Inches	
						Max.	Min.
E	1 5/16	1 1/2	1 1/2	7/16	3	0.874	0.870
A	1 5/8	1 1/2	1 3/4	9/16	3	1.139	1.134
B	1 29/32	1 1/2	1 7/8	5/8	5	1.280	1.275
N	2 3/8	1 1/2	2 3/8	1	4	1.686	1.681

Designating Symbol	L, in Inches	M, in Inches	S, in Inches		T, in Inches		V, in Inches	
			Max.	Min.	Max.	Min.	Max.	Min.
E	4 1/2	1 7/16	0.1608	0.1563	0.999	0.998	0.1657	0.1617
A	5	1 11/16	0.1608	0.1563	1.264	1.263	0.1657	0.1617
B	5 1/4	1 13/16	0.0941	0.0897	1.405	1.404	0.0990	0.0950
N	6 1/4	2 5/16	0.1164	0.1120	1.874	1.873	0.1212	0.1173

SILVER SOLDERS

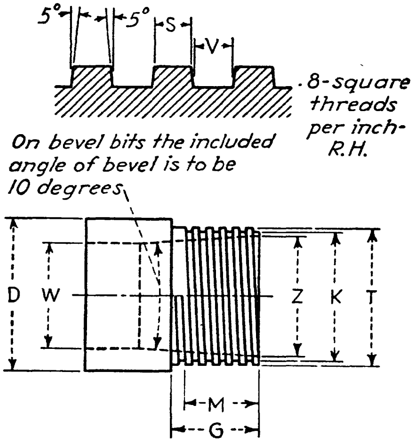
Characteristics of Silver Solders.—The tensile strength of silver solders varies from 40,000 to 60,000 pounds per square inch. Silver-soldered joints are often stronger than the metal itself.

TABLE 4.—DRILL ROD



Designating Symbol	D, in Inches	H, in Inches	K, in Inches		M	S, in Inches		T, in Inches		Threads per Inch	V, in Inches		W, in Inches
			Max.	Min.		Max.	Min.	Max.	Min.		Max.	Min.	
E	$1\frac{5}{16}$	$\frac{27}{32}$	0.877	0.876	$1\frac{5}{8}$	0.1608	0.1544	1.002	1.001	3	0.1680	0.1617	$\frac{1}{4}$
A	$1\frac{5}{8}$	$1\frac{17}{64}$	1.142	1.141	$1\frac{7}{8}$	0.1608	0.1544	1.267	1.266	3	0.1680	0.1617	$\frac{1}{4}$
B	$1\frac{29}{32}$	$1\frac{13}{32}$	1.283	1.282	2	0.0941	0.0877	1.408	1.407	5	0.1014	0.0950	$\frac{1}{4}$
N	Max. 2.385 Min. 2.375	2	1.689	1.688	$2\frac{1}{2}$	0.1163	0.1099	1.877	1.876	4	0.1236	0.1173	$\frac{5}{16}$

TABLE 5.—CORE-BARREL BITS, BEVEL WALL (8 Threads per Inch R. H.)


5°
5°
S
V
8-square threads per inch-R.H.
On bevel bits the included angle of bevel is to be 10 degrees
D
W
Z
K
T
M
G

Designating Symbol	D, in Inches		G	K, in Inches		M*	S, in Inches		T, in Inches		V, in Inches		W, in Inches		Z, in Inches	
	Max.	Min.		Max.	Min.		Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
EXT	1.423	1.419	⅞	1.186	1.181	¾	0.0594	0.0550	1.249	1.248	0.0642	0.0602	0.9390	0.9350	1.130	1.120
AXT	1.830	1.826	1	1.592	1.587	⅞	0.0594	0.0550	1.655	1.654	0.0642	0.0602	1.314	1.310	1.536	1.526
BX	2.298	2.294	1⅛	1.967	1.962	1	0.0594	0.0550	2.030	2.029	0.0642	0.0602	1.689	1.685	1.895	1.885
NX	2.923	2.919	1¼	2.592	2.587	1⅛	0.0594	0.0550	2.655	2.654	0.0642	0.0602	2.189	2.185	2.510	2.500

* Threads shall be full form to within ⅛ inch of shoulder.

The solders below are made by Handy & Harman and vary from 9 to 80 per cent of silver.

TABLE 6.—SILVER SOLDER DATA

Name	Melting Point in Degrees Fahrenheit	Color
TL	1600	Brass yellow
ATT	1500	
NE	1575	
NT	1450	Pale yellow
SS	1435	
DT	1445	
DE	1370	Yellow-white
ET	1340	
ETX	1425	
ETC	1175	
RT	1325	Silver-white
BT	1425	
IT	1460	

Silver solders are really brazing metals for use between the low temperature lead-tin solders and welding. Those high in silver resist corrosion. They are not expensive because so little is required in the joint. They flow very freely. Melting temperature varies from 1175 to 1600°F., depending on composition. The more silver, the lower the melting point.

TABLE 7.—FLUIDITY OF FLUXES

	Borax	75 % Borax, 25 % Boric Acid	50 % Borax, 50 % Boric Acid	25 % Borax, 75 % Boric Acid	Boric Acid
Begins to thicken at..........	1400	1490	1510	1510	1600
Decidedly viscous at.........	1330	1440	1460	1470	1510
Extremely viscous at.........	....	1300	1325	1325	1280
Almost solid at.............	1165	1240	1250	1220	1160
Solid at....................	1125	1120	1160	1140	1050

Fluxes must be used, the characteristics of borax being shown in Table 7.

Using Silver Solder.—Parts must be thoroughly clean. Edges of joints must be smooth and fit tightly as it is wasteful to use silver solder as filler.

Proper fluxing with borax, as a paste or in powder form, is essential. Cover all the joints and the solder itself to protect against oxidization and aid the flow of solder. Brushing spreads the flux more evenly than dipping.

Table 7 shows the fluidity of *borax* and *boric acid* solutions in degrees Fahrenheit.

Heating.—An oxyacetylene flame is too intense for some work, but oxygen and gas can generally be used satisfactorily. The joint and surrounding metal should be heated slowly before soldering. If a torch is used, the flame should be soft to prevent blowing off the flux. When one of the metals being soldered is copper, give it special attention as to heating as it conducts heat away very rapidly. The parts must be thoroughly heated back of the joint as well as the joint itself, then heat the joint quickly as hot as necessary. A good guide is to watch the borax flux, which becomes watery at 1400°F. Large surfaces should be well preheated back of the joint, taking care to preheat thoroughly the heavier piece.

Soldering.—When the joint shows a dull red, concentrate the flame along the joint. The temperature can be judged by the following table.

First visible red is about	900°F.
Dull red is about	1200°F.
Cherry red is about	1400°F.
Bright cherry red	1600°F.

When the heat is right for the solder being used, as given in Table 6, bring the solder under the flame. If the parts have been properly cleaned, fitted, fluxed, and heated, silver solder will flow quickly along the joint, following the flux.

The increasing use of silver soldering for carbide tips of cutting tools, makes it important to secure the best results possible as a poor joint may not only ruin the tip but also cause delay and spoiled work.

Soldering Stainless Steel.—All modern stainless steels can be soldered by proper methods and materials. As these steels conduct heat slowly, either more heat must be applied or it must be used for a longer time. The solder must be hard, tenacious, yet flow freely with a suitable flux. It should also have about the same color as the steel.

Pure tin and lead make the best solders for this purpose, 66 per cent tin and 34 per cent lead being a good mixture. This melts at 350°F. and Brinells at 16.7. It flows freely and is bright when buffed. Ordinary solders are not recommended.

Surfaces must be scrupulously clean both mechanically and chemically. The flux should have a solvent action on the oxide to keep the surface clean and exclude the air. Zinc chloride is a good flux either as a liquid or made into a thin, creamy paste by mixing with 50 per cent solution of hydrochloric acid. The entire area to be soldered should be covered with the flux. After tinning the surfaces, the soldering can be done in the usual way.

If difficulty is experienced in making the solder stick to polished surfaces, these can be dulled by using the following solution before soldering. Hydrochloric acid 45 parts, ferric chloride 25 parts, nitric acid 1 part. This solution should remain on the steel about 10 minutes before being wiped off.

After soldering, the surfaces should be washed thoroughly in a soda solution and then rinsed clean in clean water to remove all traces of the flux acid.

DRILLS FOR TAPPED HOLES

There are few cases in which it is advisable to use a tap drill small enough to give a completely full thread in the tapped hole. A full-depth thread takes three times the power needed to tap a 75 per cent depth thread and is only 5 per cent stronger. A nut with 50 per cent, or half-depth, thread, will break the bolt before the thread will strip. The tougher and harder the material or the deeper the threaded hole, the less the thread depth can safely be. Good manufacturing practice uses from 62 to 75 per cent of thread depth and never more than 83⅓ per cent.

Recommended Sizes.—The Bureau of Standards "Handbook H28" contains the accompanying tables for tap drills for American National coarse-thread series showing the percentage of thread depth given by the use of standard drills. These tables show the basic, maximum, and minimum diameters of the nut given in the standard tables. The drills that will provide these diameters are shown in roman type. Those which come outside these dimensions are shown in boldface type.

It must be remembered that the diameter of the hole made by any drill depends to some extent on the way it is ground, on the material drilled, and on the lubricant used. Holes that have been drilled before heat-treatment sometimes go out of round and cause tap breakage. The drills shown are carried in stock, some being in metric dimensions.

The Bureau of Standards "Handbook H28," Screw-Thread Standards for Federal Services—1942, was prepared by the Interdepartmental Screw Thread Committee established by the Departments of War, Navy, and Commerce to promote uniformity in screw-thread standards in the departments concerned. The basis for this new handbook, issued January, 1942, is the 1933 report and preceding reports of the National Screw-Thread Commission, and Handbook H25 which superseded those reports and which this handbook supersedes, together with pertinent standards approved and promulgated by the American Standards Association. The following tables of tap-drill sizes for American National coarse-thread series and American National fine-thread series of screw threads are taken from the new handbook.

The essential requirement of a tap drill is that the hole produced by it shall be such that, when tapped with a screw thread, the minor

TABLE 8.—SIZES OF TAP DRILLS—AMERICAN NATIONAL COARSE-THREAD SERIES
(Dimensions in Inches Unless Otherwise Noted)

Diameter	Threads per Inch	Minor Diameter of Nut			Stock Drills for 100 to 50 Per Cent of Basic Thread Depth		
		Basic	Maximum	Minimum	Nominal Size	Diameter	Per Cent of Depth of Basic Thread
1	64	0.0527	0.0623	0.0561	**0.0531**	**0.0531**	**98**
					0.0550	**0.0550**	**89**
					0.0571	0.0571	78
					0.0591	0.0591	68
					0.0610	0.0610	59
					0.0625	**0.0625**	**52**
2	56	0.0628	0.0737	0.0667	**0.0630**	**0.0630**	**99**
					0.0650	**0.0650**	**91**
					0.0670	0.0670	82
					0.0700	0.0700	69
					0.0730	0.0730	56
3	48	0.0719	0.0841	0.0764	**0.0730**	**0.0730**	**96**
					0.0760	**0.0760**	**85**
					0.0781	0.0781	77
					0.0810	0.0810	67
					0.0827	0.0827	60
4	40	0.0795	0.0938	0.0849	**0.0810**	**0.0810**	**95**
					0.0827	**0.0827**	**90**
					0.0860	0.0860	80
					0.0890	0.0890	71
					0.0906	0.0906	66
					0.0937	0.0937	56
5	40	0.0925	0.1062	0.0979	**0.0937**	**0.0937**	**96**
					0.0960	**0.0960**	**89**
					0.0995	0.0995	79
					0.1024	0.1024	70
					0.1040	0.1040	65
					0.1065	**0.1065**	**57**
6	32	0.0974	0.1145	0.1042	**0.0995**	**0.0995**	**95**
					0.1024	**0.1024**	**88**
					0.1040	**0.1040**	**84**
					0.1065	0.1065	78
					0.1094	0.1094	70
					0.1130	0.1130	62
					0.1160	**0.1160**	**54**
8	32	0.1234	0.1384	0.1302	**0.1250**	**0.1250**	**96**
					0.1285	**0.1285**	**87**
					0.1299	**0.1299**	**84**

TABLE 8.—SIZES OF TAP DRILLS—AMERICAN NATIONAL COARSE-THREAD SERIES.—*Continued*

Diameter	Threads per Inch	Minor Diameter of Nut			Stock Drills for 100 to 50 Per Cent of Basic Thread Depth		
		Basic	Maximum	Minimum	Nominal Size	Diameter	Per Cent of Depth of Basic Thread
8	32	0.1234	0.1384	0.1302	0.1339	0.1339	74
					0.1360	0.1360	69
					0.1378	0.1378	65
					0.1406	0.1406	58
10	24	0.1359	0.1559	0.1449	0.1378	0.1378	96
					0.1406	0.1406	91
					0.1440	0.1440	85
					0.1470	0.1470	79
					0.1520	0.1520	70
					0.1562	0.1562	62
					0.1610	0.1610	54
12	24	0.1619	0.1801	0.1709	0.1660	0.1660	92
					0.1695	0.1695	86
					0.1719	0.1719	82
					0.1730	0.1730	79
					0.1770	0.1770	72
					0.1800	0.1800	67
					0.1850	0.1850	57
					0.1875	0.1875	53
$\frac{1}{4}$	20	0.1850	0.2060	0.1959	0.1850	0.1850	100
					0.1875	0.1875	96
					0.1910	0.1910	91
					0.1935	0.1935	87
					0.1960	0.1960	83
					0.1990	0.1990	79
					0.2031	0.2031	72
					0.2090	0.2090	63
					0.2130	0.2130	57
$\frac{5}{16}$	18	0.2403	0.2630	0.2524	0.2460	0.2460	92
					0.2500	0.2500	87
					0.2520	0.2520	84
					0.2570	0.2570	77
					0.2610	0.2610	71
					0.2656	0.2656	65
					0.2720	0.2720	56
$\frac{3}{8}$	16	0.2938	0.3184	0.3073	0.2969	0.2969	96
					0.3020	0.3020	90
					0.3071	0.3071	84

TABLE 8.—SIZES OF TAP DRILLS—AMERICAN NATIONAL COARSE-THREAD SERIES.—*Continued*

Diameter	Threads per Inch	Minor Diameter of Nut			Stock Drills for 100 to 50 Per Cent of Basic Thread Depth		
		Basic	Maximum	Minimum	Nominal Size	Diameter	Per Cent of Depth of Basic Thread
3/8	16	0.2938	0.3184	0.3073	0.3125	0.3125	77
					0.3160	0.3160	73
					0.3230	0.3230	64
					0.3281	0.3281	58
					0.3320	0.3320	53
7/16	14	0.3447	0.3721	0.3602	0.3480	0.3480	96
					0.3543	0.3543	90
					0.3594	0.3594	84
					0.3680	0.3680	75
					0.3750	0.3750	67
					0.3860	0.3860	56
					0.3906	0.3906	51
1/2	13	0.4001	0.4290	0.4167	0.4062	0.4602	94
					0.4219	0.4219	78
					0.4375	0.4375	63
9/16	12	0.4542	0.4850	0.4723	0.4687	0.4687	87
					0.4844	0.4844	72
					0.5000	0.5000	58
					0.5062	0.5062	52
5/8	11	0.5069	0.5397	0.5266	13 mm.	0.5118	96
					33/64	0.5156	93
					17/32	0.5312	79
					13.5 mm.	0.5315	79
					35/64	0.5469	66
					14 mm.	0.5512	62
					9/16	0.5625	53
3/4	10	0.6201	0.6553	0.6417	5/8	0.6250	96
					16 mm.	0.6299	92
					41/64	0.6406	84
					16.5 mm.	0.6496	77
					21/32	0.6562	72
					17 mm.	0.6693	62
					43/64	0.6719	60
7/8	9	0.7307	0.7689	0.7547	47/64	0.7344	97
					19 mm.	0.7480	88
					3/4	0.7500	87

TABLE 8.—SIZES OF TAP DRILLS—AMERICAN NATIONAL COARSE-THREAD SERIES.—*Continued*

Diameter	Threads per Inch	Minor Diameter of Nut			Stock Drills for 100 to 50 Per Cent of Basic Thread Depth		
		Basic	Maximum	Minimum	Nominal Size	Diameter	Per Cent of Depth of Basic Thread
7/8	9	0.7307	0.7689	0.7547	49/64	0.7656	76
					19.5 mm.	0.7677	74
					25/32	0.7812	65
					20 mm.	0.7874	61
					51/64	0.7969	54
1	8	0.8376	0.8795	0.8647	27/32	0.8438	96
					21.5 mm.	0.8465	95
					55/64	0.8594	87
					22 mm.	0.8661	82
					7/8	0.8750	77
					22.5 mm.	0.8858	70
					57/64	0.8906	67
					23 mm.	0.9055	58
					29/32	0.9062	58
1 1/8	7	0.9394	0.9858	0.9704	24 mm.	0.9944	97
					61/64	0.9531	93
					24.5 mm.	0.9646	86
					31/32	0.9688	84
					25 mm.	0.9842	76
					63/64	0.9844	76
					1	1.0000	67
					25.5 mm.	1.0039	65
					1 1/64	1.0156	59
					26 mm.	1.0236	55
					1 1/32	1.0312	51
1 1/4	7	1.0644	1.1108	1.0954	15/64	1.0781	93
					27.5 mm.	1.0827	90
					13/32	1.0938	84
					28 mm.	1.1024	80
					17/64	1.1094	76
					28.5 mm.	1.1220	69
					1 1/8	1.1250	67
					19/64	1.1406	59
					29 mm.	1.1417	58
					1 5/32	1.1562	51
1 3/8	6	1.1585	1.2126	1.1946	29.5 mm.	1.1614	99
					1 11/64	1.1719	94
					30 mm.	1.1811	90

TABLE 8.—SIZES OF TAP DRILLS—AMERICAN NATIONAL COARSE-THREAD SERIES.—*Continued*

Diameter	Threads per Inch	Minor Diameter of Nut			Stock Drills for 100 to 50 Per Cent of Basic Thread Depth		
		Basic	Maximum	Minimum	Nominal Size	Diameter	Per Cent of Depth of Basic Thread
$1\frac{3}{8}$	6	1.1585	1.2126	1.1946	$1\frac{3}{16}$	1.1875	87
					30.5 mm.	1.2008	80
					$1\frac{13}{64}$	1.2031	79
					$1\frac{7}{32}$	1.2188	72
					31 mm.	1.2205	71
					$1\frac{15}{64}$	1.2344	65
					31.5 mm.	1.2402	62
					$1\frac{1}{4}$	1.2500	58
					32 mm.	1.2598	53
					$1\frac{17}{64}$	1.2656	51
$1\frac{1}{2}$	6	1.2835	1.3376	1.3196	$1\frac{19}{64}$	1.2969	94
					33 mm.	1.2992	93
					$1\frac{5}{16}$	1.3125	87
					33.5 mm.	1.3189	84
					$1\frac{21}{64}$	1.3281	79
					34 mm.	1.3386	75
					$1\frac{11}{32}$	1.3438	72
					34.5 mm.	1.3583	65
					$1\frac{23}{64}$	1.3594	65
					$1\frac{3}{8}$	1.3750	58
					35 mm.	1.3780	56
					$1\frac{25}{64}$	1.3906	51
$1\frac{3}{4}$	5	1.4902	1.5551	1.5335	38 mm.	1.4961	98
					$1\frac{1}{2}$	1.5000	96
					$1\frac{33}{64}$	1.5156	90
					38.5 mm.	1.5157	90
					$1\frac{17}{32}$	1.5312	84
					39 mm.	1.5354	83
					$1\frac{35}{64}$	1.5469	78
					39.5 mm.	1.5551	75
					$1\frac{9}{16}$	1.5625	72
					40 mm.	1.5748	67
					$1\frac{37}{64}$	1.5781	66
					$1\frac{19}{32}$	1.5938	60
					40.5 mm.	1.5945	60
					$1\frac{39}{64}$	1.6094	54
					41 mm.	1.6142	52

TABLE 8.—SIZES OF TAP DRILLS—AMERICAN NATIONAL COARSE-THREAD SERIES.—*Continued*

Diameter	Threads per Inch	Minor Diameter of Nut			Stock Drills for 100 to 50 Per Cent of Basic Thread Depth		
		Basic	Maximum	Minimum	Nominal Size	Diameter	Per Cent of Depth of Basic Thread
2	$4\frac{1}{2}$	1.7113	1.7835	1.7594	43.5 mm.	1.7126	100
					$1\frac{23}{32}$	1.7188	97
					44 mm.	1.7323	93
					$1\frac{47}{64}$	1.7344	92
					$1\frac{3}{4}$	1.7500	87
					44.5 mm.	1.7520	86
					$1\frac{49}{64}$	1.7656	81
					45 mm.	1.7716	79
					$1\frac{25}{32}$	1.7812	76
					45.5 mm.	1.7913	72
					$1\frac{51}{64}$	1.7969	70
					46 mm.	1.8110	65
					$1\frac{13}{16}$	1.8125	65
					$1\frac{53}{64}$	1.8281	60
					46.5 mm.	1.8307	59
					$1\frac{27}{32}$	1.8438	54
					47 mm.	1.8504	52
$2\frac{1}{4}$	$4\frac{1}{2}$	1.9613	2.0335	2.0094	50 mm.	1.9685	98
					$1\frac{31}{32}$	1.9688	97
					$1\frac{63}{64}$	1.9844	92
					50.5 mm.	1.9882	91
					2	2.0000	78
					51 mm.	2.0079	84
					$2\frac{1}{64}$	2.0156	81
					51.5 mm.	2.0276	77
					$2\frac{1}{32}$	2.0312	76
					$2\frac{3}{64}$	2.0469	70
					52 mm.	2.0472	70
					$2\frac{1}{16}$	2.0625	65
					52.5 mm.	2.0669	63
					$2\frac{5}{64}$	2.0781	60
					53 mm.	2.0866	57
					$2\frac{3}{32}$	2.0938	54
$2\frac{1}{2}$	4	2.1752	2.2564	2.2294	55.5 mm.	2.1850	97
					$2\frac{3}{16}$	2.1875	96
					$2\frac{13}{64}$	2.2031	91
					56 mm.	2.2047	91
					$2\frac{7}{32}$	2.2188	87

TABLE 8.—SIZES OF TAP DRILLS—AMERICAN NATIONAL COARSE-THREAD SERIES.—*Continued*

Diameter	Threads per Inch	Minor Diameter of Nut			Stock Drills for 100 to 50 Per Cent of Basic Thread Depth		
		Basic	Maximum	Minimum	Nominal Size	Diameter	Per Cent of Depth of Basic Thread
$2\frac{1}{2}$	4	2.1752	1.2564	2.2294	56.5 mm.	2.2244	85
					$2\frac{15}{64}$	2.2344	82
					57 mm.	2.2441	79
					$2\frac{1}{4}$	2.2500	77
					57.5 mm.	2.2638	73
					$2\frac{17}{64}$	2.2656	72
					$2\frac{9}{32}$	2.2812	67
					58 mm.	2.2835	67
					$2\frac{19}{64}$	2.2969	63
					58.5 mm.	2.3031	61
					$2\frac{5}{16}$	2.3125	58
					59 mm.	2.3228	55
					$2\frac{21}{64}$	2.3281	53
$2\frac{3}{4}$	4	2.4252	2.5064	2.4794	$2\frac{7}{16}$	2.4375	96
					62 mm.	2.4409	95
					$2\frac{29}{64}$	2.4531	91
					62.5 mm.	2.4606	89
					$2\frac{15}{32}$	2.4688	87
					63 mm.	2.4803	83
					$2\frac{31}{64}$	2.4844	82
					63.5 mm.	2.5000	77
					$2\frac{1}{2}$	2.5000	77
					$2\frac{33}{64}$	2.5156	72
					64 mm.	2.5197	71
					$2\frac{17}{32}$	2.5312	67
					64.5 mm.	2.5394	65
					$2\frac{35}{64}$	2.5469	63
					65 mm.	2.5590	59
					$2\frac{9}{16}$	2.5625	58
					$2\frac{37}{64}$	2.5781	53
					65.5 mm.	2.5787	53
3	4	2.6752	2.7564	2.7294	68 mm.	2.6772	99
					$2\frac{11}{16}$	2.6875	96
					68.5 mm.	2.6968	93
					$2\frac{45}{64}$	2.7031	91
					69 mm.	2.7165	87
					$2\frac{23}{32}$	2.7188	87
					$2\frac{47}{64}$	2.7344	82

TABLE 8.—SIZES OF TAP DRILLS—AMERICAN NATIONAL COARSE-THREAD SERIES.—*Continued*

Diameter	Threads per Inch	Minor Diameter of Nut			Stock Drills for 100 to 50 Per Cent of Basic Thread Depth		
		Basic	Maximum	Minimum	Nominal Size	Diameter	Per Cent of Depth of Basic Thread
3	4	2.6752	2.7564	2.7294	69.5 mm.	2.7362	81
					$2\frac{3}{4}$	2.7500	77
					70 mm.	2.7559	75
					$2\frac{49}{64}$	2.7656	72
					70.5 mm.	2.7756	69
					$2\frac{25}{32}$	2.7812	67
					71 mm.	2.7953	63
					$2\frac{51}{64}$	2.7969	63
					$2\frac{13}{16}$	2.8125	58
					71.5 mm.	2.8150	57
					$2\frac{53}{64}$	2.8281	53
					72 mm.	2.8346	51
$3\frac{1}{4}$	4	2.9252	3.0064	2.9794	74.5 mm.	2.9331	98
					$2\frac{15}{16}$	2.9375	96
					75 mm.	2.9528	92
					$2\frac{61}{64}$	2.9531	91
					$2\frac{31}{32}$	2.9688	87
					75.5 mm.	2.9724	85
					$2\frac{63}{64}$	2.9844	82
					76 mm.	2.9921	79
					3	3.0000	77
					$3\frac{1}{32}$	3.0312	67
					$3\frac{1}{16}$	3.0625	58
$3\frac{1}{2}$	4	3.1752	3.2564	3.2294	$3\frac{3}{16}$	3.1875	96
					$3\frac{7}{32}$	3.2188	87
					$3\frac{1}{4}$	3.2500	77
					$3\frac{9}{32}$	3.2812	67
					$3\frac{5}{16}$	3.3125	58
$3\frac{3}{4}$	4	3.4252	3.5064	3.4794	$3\frac{7}{16}$	3.4375	96
					$3\frac{1}{2}$	3.5000	77
0	80	0.0438	0.0514	0.0465	0.0453	0.0453	91
					0.0469	0.0469	81
					0.0492	0.0492	67
					0.0512	0.0512	54
1	72	0.0550	0.0634	0.0580	0.0550	0.0550	100
					0.0571	0.0571	88
					0.0591	0.0591	77

TABLE 8.—SIZES OF TAP DRILLS—AMERICAN NATIONAL COARSE-THREAD SERIES.—*Continued*

Diameter	Threads per Inch	Minor Diameter of Nut			Stock Drills for 100 to 50 Per Cent of Basic Thread Depth		
		Basic	Maximum	Minimum	Nominal Size	Diameter	Per Cent of Depth of Basic Thread
1	72	0.0550	0.0634	0.0580	0.0610	0.0610	67
					0.0625	**0.0625**	**58**
					0.0630	**0.0630**	**55**
2	64	0.0657	0.0746	0.0691	**0.0670**	**0.0670**	**94**
					0.0700	0.0700	79
					0.0730	0.0730	64
3	56	0.0758	0.0856	0.0797	**0.0760**	**0.0760**	**99**
					0.0781	**0.0781**	**90**
					0.0810	0.0810	78
					0.0827	0.0827	70
					0.0860	0.0860	56
4	48	0.0849	0.0960	0.0894	**0.0860**	**0.0860**	**96**
					0.0890	**0.0890**	**85**
					0.0906	0.0960	79
					0.0937	0.0937	68
					0.0960	0.0960	59
5	44	0.0955	0.1068	0.1004	**0.0960**	**0.0960**	**98**
					0.0995	**0.0995**	**86**
					0.1024	0.1024	77
					0.1040	0.1040	71
					0.1065	0.1065	63
					0.1094	**0.1094**	**53**
6	40	0.1055	0.1179	0.1109	**0.1065**	**0.1065**	**97**
					0.1094	**0.1094**	**88**
					0.1130	0.1130	77
					0.1160	0.1160	68
					0.1200	**0.1200**	**55**

diameter of the tapped hole shall be within the specified limits. It should be noted that the minor diameters of the tapped holes are the same for Classes 1 to 4.

If the drill is too large, the minor diameter of the tapped hole will also be too large and the thread in the nut will be too shallow, that is, too small a percentage of a full thread. As an extreme case the thread in the tapped hole will engage only the tops of the threads on a screw of correct size, and under stress the threads of the screw will strip and the full strength of the fastening will not be developed.

If, on the other hand, the tap drill is too small, the tap will be forced to cut a thread of full depth, and in the extreme case to act as a reamer also. This will result in excessive power consumption and tap breakage and will also make the minor diameter of the tapped hole dependent upon the minor diameter of the tap. This is undesirable since the minor diameter of the tap is not, in general, held to the same close limits as the other tap elements, and as a result the minor diameter of a hole tapped under these conditions may be in error even though the tap is otherwise correct.

It is a well-known fact that the size of the hole produced by a tap drill depends to some extent upon the method of grinding the drill, the material drilled, the lubricant used, and the speed and feed of the operation. This being true, it is apparent that fixing the diameter of the tap drill does not completely fix the diameter of the hole.

There are given in the accompanying table all drills regularly carried in stock, both English and metric, which fall between the limiting dimensions of the minor diameter of the threaded hole for the American National coarse- and fine-thread series, as well as drills outside of the minor diameter limits corresponding in size to thread depth from 50 to 100 per cent. Drill sizes up to ½ inch are in agreement with A.S.A. B5.12-1940, Twist Drills, Straight Shank, published by the A.S.M.E. The stock drill sizes given in italics are not within the specified limits for minor diameter of nut.

HOLE CIRCLE LAYOUTS

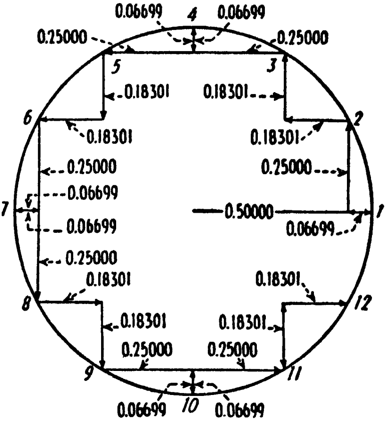
The following tables are for accurate layout of holes on a given circumference. The values given are constants for a 1-inch circle. For larger or smaller circles, multiply the values by the diameter of the given circle. All values are given in ten-thousandths of an inch.

The tables are useful on precision machines, particularly the jig borer. They are to be used as follows:

Have the work fastened in position and locate the true center. Then move to the right a distance equal to the radius of the circle to be divided. Bore hole 1. Then move horizontally to the left the required number of ten-thousandths for hole 2. Follow this by moving vertically the required number of ten-thousandths for hole 2, thus locating this hole. Repeat these horizontal and vertical movements, locating each hole in turn. At each outer intersection bore the hole, and repeat until the circle is complete.

For example, in laying out 12 holes on a 1-inch circle as shown in one of the drawings, hole 1 is bored 0.5000 inch to the right of the center. Hole 2 is located by first moving 0.06699 inch to the left and then 0.2500 inch vertically. Hole 3 is located by moving 0.18301 inch horizontally to the left and 0.18301 inch vertically. This is repeated, using the proper constants, for locating hole 4. But when locating hole 5, move vertically downward 0.06699 inch and then horizontally to the left 0.2500 inch. This is repeated for holes 6 and 7, using the proper constants. Hole 8 is located by moving horizontally to the right 0.06699 inch and then vertically

TABLE 9.—HOLE CIRCLE LAYOUTS



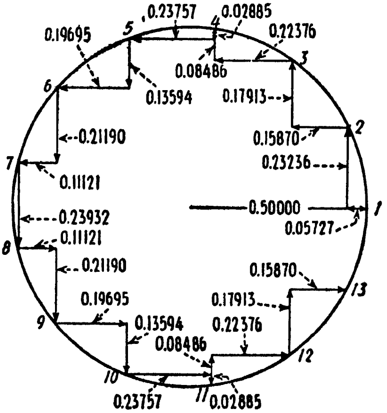


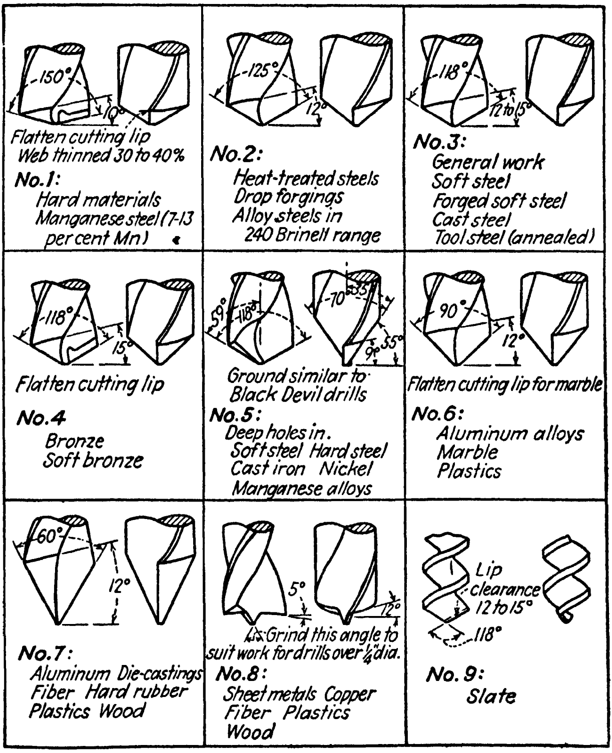
TABLE 9.—HOLE CIRCLE LAYOUTS.—*Continued*

Hole No.	Horizontal	Vertical
Three holes:		
1	0.50000	
2	0.75000	0.43301
3		0.86602
Five holes:		
1	0.50000	
2	0.34549	0.47553
3, 5	0.55902	0.18164
4		0.58778
Six holes:		
1, 3, 6	0.50000	
2, 4, 5	0.25000	0.43301
Seven holes:		
1	0.50000	
2	0.18826	0.39091
3, 7	0.42300	0.09655
4, 6	0.33923	0.27052
5		0.43388
Eight holes:		
1	0.50000	
2, 5, 6	0.14645	0.35355
3, 4, 7, 8	0.35355	0.14645
Nine holes:		
1	0.50000	
2	0.11698	0.32139
3, 9	0.29620	0.17101
4, 8	0.33682	0.05939
5, 7	0.21984	0.26200
6		0.34202
Ten holes:		
1	0.50000	
2, 6, 7	0.09549	0.29389
3, 5, 8, 10	0.25000	0.18164
4, 9	0.30902	
Eleven holes:		
1	0.50000	
2	0.07937	0.27032
3, 11	0.21292	0.18450
4, 10	0.27887	0.04009
5, 9	0.25626	0.11704
6, 8	0.15233	0.23701
7		0.28172
Twelve holes:		
1	0.50000	
2, 7, 8	0.06699	0.25000
3, 6, 9, 12	0.18301	0.18301
4, 5, 10, 11	0.25000	0.06699

TABLE 9.—HOLE CIRCLE LAYOUTS.—*Continued*

Hole No.	Horizontal	Vertical
Thirteen holes:		
1	0.50000	
2	0.05727	0.23236
3, 13	0.15870	0.17913
4, 12	0.22376	0.08486
5, 11	0.23757	0.02885
6, 10	0.19695	0.13594
7, 9	0.11121	0.21190
8		0.23932
Fourteen holes:		
1	0.50000	
2, 8, 9	0.04951	0.21694
3, 7, 10, 14	0.13875	0.17397
4, 6, 11, 13	0.20048	0.09655
5, 12	0.22252	
Fifteen holes:		
1	0.50000	
2	0.04323	0.20337
3, 15	0.12221	0.16820
4, 14	0.18005	0.10396
5, 13	0.20677	0.02173
6, 12	0.19774	0.06425
7, 11	0.15451	0.13912
8, 10	0.08456	0.18994
9		0.20790
Sixteen holes:		
1	0.50000	
2, 9, 10	0.03806	0.19134
3, 8, 11, 16	0.10839	0.16221
4, 7, 12, 15	0.16221	0.10839
5, 6, 13, 14	0.19134	0.03806

downward 0.2500 inch. Thus in laying out the holes on the circumference, the mechanic must observe whether the next movement is vertically upward or downward, or horizontally left or right. He selects the proper movement by observing the development of the circle as the holes are bored.



Drill Points for Various Materials (*Courtesy of Westinghouse Electric & Manufacturing Company.*)

SECTION IV

CUTTING TOOLS

CARBIDE TOOLS

High-Speed Precision Boring.—Precision boring of small steel parts is, according to Philip M. McKenna, being done at a cutting speed of 1,000 feet per minute with grade K3H Kennametal bits. In one setup, bits ground as shown are used for precision-boring a part made from S.A.E. 3120 steel, using a feed of 0.001 inch per revolution and a 0.003-inch depth of cut. The boring bar for this part carries two solid bits and is rotated at 4,300 r.p.m. to give the cutting speed of 1,000 feet per minute. In this part a section of the bore is semicircular, so that one of the bits has an interrupted cut about $\frac{3}{4}$ inch long. Production per grind averages 215 pieces, and the bits can be reground from twelve to twenty times. Best results are obtained when the bit is ground carefully to dimensions developed by the cut-and-try method, using a special fixture to hold the bits while being ground. The size of the radius at the nose of the bit and the cutting edge angles are critical; frequently, a slight variation will have a major effect upon the production obtained between tool grinds and the quality of the finish produced. Figure 1 shows such a tool bit.

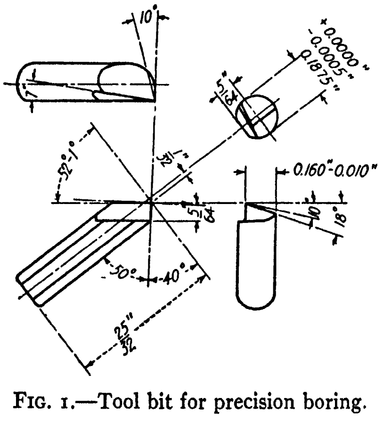


FIG. 1.—Tool bit for precision boring.

RAKE ON CUTTING TOOLS

Machining hard metals such as armor plate has resulted in the development of cutting tools with a negative rake. Started as a means of preventing breakage of the carbide tips, it has been found to allow higher cutting speeds and to leave a better surface, and is particularly useful for turning or planing interrupted cuts where the shock of the tool entering the work caused breakage. The average negative rake seems to be from 10 to 15 degrees, but sometimes when the turning tool meets a hooked surface, the angle may be increased to as much as 35 degrees with turning tools.

Positive Rake for Soft Metals.—Negative rake, in the opinion of Arthur A. Schwartz, chief tool research engineer at Bell Aircraft, is justified on carbide cutters *only* to support the cutting edge. It takes more power and imparts more heat than positive rake.

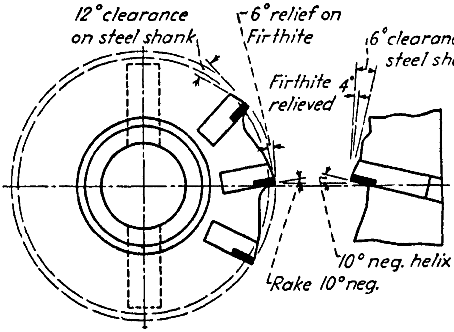


FIG. 2.—Negative-rake milling cutters.

The factors to be considered in milling are chip *thickness* (not depth of cut), speed, and power. The feed must be sufficient to maintain a sufficient thickness of chip, which for aluminum or magnesium should be from 0.005 to 0.012 inch. Aluminum is now being milled at from 8,000 to 18,000 surface feet per minute. This means that the feed per minute is the chip thickness times the r.p.m. times the number of teeth. Cutters with from one to six teeth are now being used. With two teeth and 3,500 r.p.m., as on Farnham spar millers, there are 7,000 chips per minute. If the chip is 0.010 inch thick, the feed will be 70 inches per minute.

With a single-tooth cutter, Bell Aircraft is removing over 200 cubic inches of aluminum per minute at a feed of 30 inches. The cut is 3 inches deep by 3½ inches wide. Here the heat goes into the chips, and both work and cutter remain cool.

Mr. Schwartz has found that heat increases up to 3,000 cutting feet per minute and then decreases. No higher speed produces so much heat as is produced at that point.

Negative Rake.—Milling cutters are also made with negative rake and also a negative helix, the angles in both cases depending

TABLE 1.—TYPICAL PERFORMANCE DATA OF HYPER-MILLING CUTTERS

Material		Hyper-Mill				Operating Conditions							
				Angles, Deg.		Cut, In.	Speed		Feed				
							Firthite			Per Tooth per Rev.			
Type	Condition	Diameter, In.	Number of Teeth	Rake	Helix	Firthite	R.p.m.	F.p.m.	Firthite, In. per Min.	Firthite, In.	Cutting Fluid	Performance Results	Remarks
Steel forging....	270–300 BHN	7	8	−10	−10	$\frac{1}{16}$	324	593	3	0 0012	None	30 pieces per grind—Firthite T-16 4 pieces per grind—high-speed steel	
Steel forging....	150,000 p.s.i. tens. str.	6	10	−10	−10	$\frac{1}{8}$	350	550	7	0.002	None		30 pieces per hour—Firthite T-16 10 pieces per hour—high-speed steel
Forged steel....	150,000 p.s.i. tens. str.	6	10	−10	−10	$\frac{5}{16}$	400	630	$5\frac{7}{16}$	0.0014	665 Tycol, +5 pt. H_2O	60 pieces per grind—Firthite T-16 15 pieces per grind—high-speed steel	Machine time per piece—2 min. Firthite T-16 Machine time per piece—5 min. high-speed steel
Boiler plate....	As rolled	6	10	−10	−10	$\frac{5}{16}\times 5$	285	450	$5\frac{3}{4}$	0.0020	None	10 cuts at 72 in.—negligible wear	New 5-in. Sellers horizontal stalled but no tips broke or loosened
S.A.E. 1090....	200 BHN	$1\frac{1}{16}$	2	0	0	$\frac{1}{16}\times\frac{5}{8}$	2300	640	11	0.0022	None	38 sec.—7 linear inches. 0.427 cu. in. per minute	Remilling salvaged tool shank for retipping

TABLE 1.—TYPICAL PERFORMANCE DATA OF HYPER-MILLING CUTTERS.—*Continued*

Material		Hyper-Mill				Operating Conditions							
Type	Condition	Diameter, In.	Number of Teeth	Angles, Deg.		Cut, In.	Speed		Feed		Cutting Fluid	Performance Results	Remarks
				Rake	Helix	Firthite	Firthite		Firthite, In. per Min.	Per Tooth per Rev.			
							R.p.m.	F.p.m.		Firthite, In.			
WDX-4340	350 BHN	3½	8	− 5		$\frac{1}{16}$	210	190	5¼	0 0031	Soluble oil	Forty 12-in. pieces per grind, T-89	Straddle climb milling with conventional cutter
Cast armor	220 BHN	6½	14	+ 3	− 5	$\frac{1}{16}\times2$	342	585	15	0 0030	None	540 linear inches per grind, T-90	5-deg. negative rake land, 0.005 wide. Used conventional cutter. 5-deg. negative spiral on point only
S.A.E. 3145	Annealed	6	12	−10	− 5	$\frac{1}{16}\times4\frac{1}{4}$	365	575	4¼	0.0010	None	8 to 12 hr. between grinds	
S.A.E. 2340	As cast	8	14	−10	−10	$\frac{1}{16}\times6$	288	487	3⅝	0 0009	None	24 hr. between grinds	
S.A.E. 4340	400 BHN	6	10	−10	−10	$\frac{1}{16}$	230	388	3$\frac{3}{16}$	0.0014	None	8 hr. between grinds	Fragile part—yet heat and strain so slight that distortion was negligible
S.A.E. 4320	32 Shore	6	10	−10	−10	$\frac{1}{4}\times3\frac{3}{4}$	445	730	7⅝	0.0017	None	Excellent finish—no burr	7.15 cu. in. per minute—7.5 net horsepower, efficiency 0.96
Gear steel casting	As cast	12	28			$\frac{7}{32}$	52	163	2	0.0015	None	36-hr. cutter life—Firthite HD 3-hr. cutter life—high-speed steel	Finish and tolerances maintained better than ever before realized possible with milling. Conventional cutter

on the work to be done. Malcolm F. Judkins, chief engineer of the Firth-Sterming Company, must be credited with much of the development of such milling cutters, which permit high cutting speeds, milling of heat-treated alloys, a highly burnished surface, and a high rate of production. High cutting speeds and light cuts were at first thought to be necessary, but later developments show that slower speeds, deeper cuts, and heavier feeds are also possible. This is called "hyper-milling," and a typical cutter is seen in Fig. 2. Table 1 shows performance data with cutters of this kind. Table 2 shows feeds used in milling armor plate.

TABLE 2.—FEED RATES FOR MILLING ARMOR PLATE

Type of Cutter	Size of Cut, in Inches		Feed Rate	
	Depth	Width	Inches per Tooth	Inches per Minute
Shear clear face mill..	½ to 1¼	6 to 12	0.015 to 0.030	1½ to 3
Shear clear face mill..	1	12 to 18	0.018	1½
Shear clear face mill..	½	12 to 18	0.024	2
Shear clear face mill..	¼	12 to 18	0.030	2½
Standard face mill (square corners)....	¼ to ½	6 to 12	0.010 to 0.020	1 to 2
Standard face mill (square corners)....	1	6 to 12	0.010 to 0.015	1 to 1½
Helical slab mill (6 inch diameter or over).............	¼ to ½	6 to 10	0.010 to 0.020	1 to 2
Helical slab mill (6 inch diameter or over).............	1	6 to 10	0.010	1
Solid H.S.S. end mill (under 3 inches diameter)..........	½	2 to 3	0.006 to 0.010	¾ to 1

NOTE: About 1 cubic inch of metal removed per horsepower-minute.

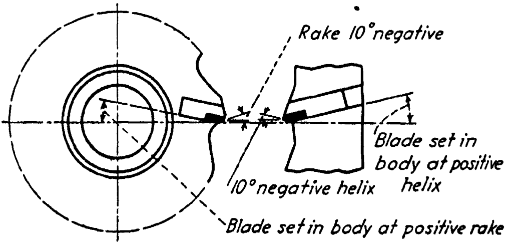

Rake 10° negative
Blade set in body at positive helix
10° negative helix
Blade set in body at positive rake

FIG. 3.—Grinding negative rake on standard cutters.

Figure 3 shows how negative rake can be ground on regular cutters.

It is essential that the cutters be properly ground as instructed by the maker and that each tooth be lightly hand-honed with a 440-grit, diamond-impregnated honing stick.

Development along this line for milling aluminum and softer metals has resulted in very high speeds and feeds. Engineers at the Vega plant of the Lockheed Company have done much along this line. Some tests show milling speeds as high as 18,000 feet cutting speed per minute, and a speed of 5,000 to 8,000 feet is not uncommon. Milling cutters for this work are now made with a cast-iron body having carbide tips welded to the teeth. The teeth must be widely spaced and few in number for best results. Each tooth should have a bite of from 0.005 to 0.012 inch. Some believe that metal can be removed at from five to ten times the rate used a few years ago.

Standard Milling Cutters.—Table 3 gives speeds and feeds suggested by the War Production Board for use with standard milling cutters. As these cutters greatly outnumber the newer negative-rake cutters, the suggestions still have a wide application.

FACE-MILLING CUTTER MOUNTINGS

Approved methods of mounting face-milling cutters are shown in Figs. 4 and 5. These are suggested by F. W. Lucht, engineer of the Carboloy Company, and show all necessary details for mounting cutters on spindle noses and also in the tapered hole in the spindle.

Carbide-Tipped Face Mills.—In face milling on a universal knee-type milling machine, the table must be set at zero position, making the table travel normal to the center line of the cutter spindle, or slightly past zero by an amount not greater than 0.002 inch in 18 inches so that the trailing portion of the cutter will not spoil the work. In face milling on a plain milling machine of either the horizontal knee or the vertical type, the angular relation of the milling-machine spindle to the direction of table travel is such that the trailing portion of a cutter if properly ground will not spoil the finish on the work. This also applies to the manufacturing and planer type of millers.

When the tapered hole in the machine spindle is used to centralize a face mill, it must be clean, so that a uniform metal-to-metal fit for the full shank length is obtained.

Mr. Lucht suggests that the following precautions should be observed when cemented carbide-tipped cutters are used:

1. Never disengage spindle while feed is engaged.
2. Always have the cutter rotating before feeding work up to the cutter.
3. When using machines with rapid traverse, make certain that the rapid traverse is out, and the regular feed in, before the work comes in contact with the rotating cutter.
4. When stopping the machine, first throw out the feed, and then immediately disengage the clutch spindle.

TABLE 3.—SPEEDS AND FEEDS FOR CUTTING S.A.E. STEELS*

Steel	Depth of Cut, in Inches	Feeds, in Inches per Revolution									
		High-Speed Steel				Stellite J-Metal†				Cemented Carbides	
		1/64	1/32	1/16	3/32	1/64	1/32	1/16	3/32	1/64	1/32
Group 1	1/32	100 to 161	86 to 138	70 to 113	60 to 97	153 to 246	132 to 212	114 to 184	100 to 161	391 to 630	357 to 575
	1/16	91 to 147	80 to 138	67 to 108	57 to 92	140 to 225	122 to 195	106 to 170	93 to 150	371 to 597	329 to 530
	1/8	81 to 131	71 to 115	61 to 91	51 to 83	126 to 201	110 to 177	94 to 152	84 to 136	341 to 552	300 to 530
	1/4	67 to 108	60 to 96	51 to 83	43 to 69	106 to 170	93 to 150	78 to 117	69 to 110	314 to 505	266 to 428
	1/2	47 to 76	43 to 69	39 to 62	31 to 51	77 to 124	69 to 110	59 to 94	50 to 80	226 to 363	214 to 345
Group 2	1/32	82 to 96	70 to 82	57 to 67	49 to 57	125 to 146	108 to 126	94 to 110	82 to 96	320 to 375	292 to 342
	1/16	75 to 88	65 to 77	55 to 64	47 to 55	115 to 134	100 to 116	87 to 101	76 to 89	304 to 356	269 to 315
	1/8	67 to 78	58 to 68	50 to 59	42 to 49	103 to 120	90 to 105	77 to 90	69 to 80	281 to 328	246 to 288
	1/4	55 to 64	49 to 57	42 to 49	35 to 41	86 to 101	76 to 89	64 to 75	56 to 66	257 to 301	217 to 255
	1/2	39 to 45	35 to 41	32 to 37	26 to 30	63 to 74	56 to 66	48 to 56	41 to 56	185 to 216	175 to 205
Group 3	1/32	67 to 78	57 to 63	47 to 54	40 to 47	102 to 119	87 to 102	76 to 89	67 to 78	260 to 304	238 to 277
	1/16	61 to 71	53 to 62	45 to 52	38 to 44	93 to 109	81 to 94	70 to 82	62 to 72	247 to 288	219 to 255
	1/8	54 to 63	48 to 55	41 to 48	34 to 40	84 to 98	73 to 85	63 to 73	56 to 65	228 to 266	200 to 233
	1/4	45 to 52	40 to 47	34 to 40	28 to 33	70 to 82	62 to 72	52 to 61	46 to 53	209 to 244	177 to 203
	1/2	31 to 37	28 to 33	26 to 30	21 to 24	51 to 60	46 to 53	39 to 45	33 to 39	150 to 175	142 to 166
Group 4	1/32	48 to 64	41 to 55	34 to 45	29 to 38	74 to 97	63 to 84	55 to 73	48 to 64	189 to 248	172 to 238
	1/16	44 to 58	39 to 51	32 to 43	28 to 36	68 to 89	59 to 77	51 to 67	45 to 59	179 to 236	159 to 210
	1/8	39 to 52	35 to 45	30 to 39	25 to 33	61 to 80	53 to 70	46 to 60	41 to 54	166 to 218	145 to 191
	1/4	32 to 43	29 to 38	25 to 33	21 to 27	51 to 67	45 to 59	38 to 50	33 to 44	152 to 200	128 to 169
	1/2	23 to 30	21 to 27	19 to 25	15 to 20	37 to 49	33 to 44	28 to 37	24 to 32	109 to 144	103 to 137

* Data are for continuous cutting with lubricant.

† With Stellite 2400 these speeds can be increased 25 to 30 per cent. ‡ Annealed steels.

NOTE: For continuous cuts without lubricant, decrease speeds 25 per cent; for intermittent cuts with lubricant, decrease cutting speeds 15 per cent; for intermittent cuts without lubricant, decrease cutting speeds 40 per cent; for light finishing cuts and fine feeds, cutting speeds can be increased 50 to 100 per cent.

Group 1—High speeds for S.A.E. X1112; intermediate speeds for 1112, X1314, X1315; low speeds for 1115.

Group 2—High speeds for X1015 and X1020; intermediate speeds for X1330, 2015, 2115, 1010, 1015, 1020, 1025, 1045,‡ X1335, 3115, 3120, 3130,‡ 4815, 4820, 6130,‡ 1030, 1035, 1050,‡ X1340, 2330,‡ 2335,‡ 3135,‡ 5140,‡ 6140;‡ low speeds for X1025, 2315, 3140,‡ X4130, 4140,‡ 4615, 4620, 6135.‡

Group 3—High speeds for 1040, X3140,‡ 3145,‡ 3215, 3220, 3415; intermediate speeds for 3150,‡ 3312, 4150,‡, X4340,‡ 4640,‡ 5120, 5150,‡ 6135,‡ 6150,‡ 1045, 2340,‡ 3130, 3240,‡ X4340, 4640; low speeds for 1050, 2330, 3135, 6135.

Group 4—1055,‡ 1060,‡ 1065,‡ 2345,‡ 2515, 3140, 3150,‡ 6150; intermediate speeds for X1065,‡ 1070,‡ 1075,‡ 1080,‡ 1330, 1335, 1340, 2340, X3140, 3150, 3240,‡ 3245,‡ 3250,‡ 9250,‡ 1085,‡ 1090,‡ 1095,‡ 3240, 3245, 3250, 9250; low speeds for 52100.‡

5. Never allow the cutter to idle in the cut, for the rubbing of the cutting edges against the work has a lapping effect on the cutting edges that dulls the cutter.

6. Keep the cutter rotating when returning the table to starting position after a roughing cut.

7. After a finish cut, the work should be removed before returning the table.

Keep the backlash in the feed screw at a minimum; lock the knee and saddle securely before starting a cut; adjust table gibs to give the table a snug sliding fit; check lubrication to make certain that it is adequate and properly applied; keep end play in the machine spindle at an absolute minimum; and wipe chips from the ways before moving the table saddle or knee.

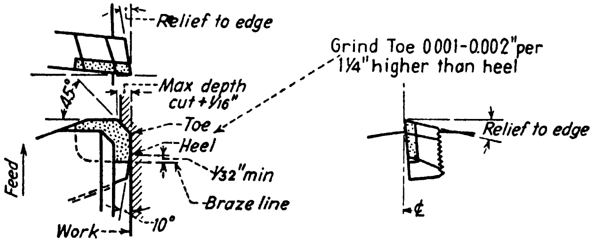


FIG. 4.—Face-mill teeth for general work.

Example of Use of Table 4

Material to be milled	Cast iron—medium gray
Type of milling cut	Roughing
Diameter of face mill	10 inches
Number of teeth in face mill	22

Method

1. Select the starting cutter speed in feet per minute for cast iron—medium gray from Table 5, 180.

2. Place the straight edge on the nomograph (Table 4) in position *AB*, passing through 180 feet per minute and 10 inches cutter diameter. Read 69 r.p.m. as the approximate speed to set the milling. (Select the milling-machine speed nearest to this speed.)

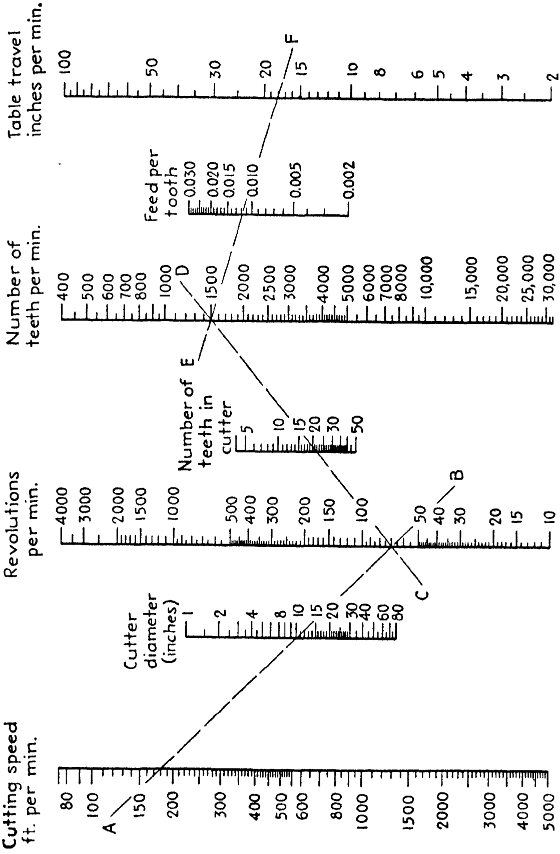
3. Place the straight edge in position *CD*, lining up 69 r.p.m. with 22 (number of teeth in cutter), and read 1510+ as the number of teeth per minute.

4. Select starting roughing feed per tooth from Table 5 as 0.012 inch.

5. Place the straight edge in position *EF*, lining up 1510+ teeth per minute with 0.012 inch feed per tooth, and read milling-machine-table travel as 18.2 inches per minute. (Select the milling-machine-table feed rate nearest to the above feed rate.)

Proper clamping is especially important when cemented carbide cutters are used because increased rates of feed are usually employed. The ideal method of clamping any piece of work is to hold it rigidly but still allow it to remain in a state of "rest"

TABLE 4.—CHART FOR SPEEDS AND FEEDS OF MILLING CUTTERS



without torsional or bending strains. All cutting pressures should be against rigid stops and supports—never against the clamps. Clamp the part so as to keep the surface being milled as close as possible to the machine table, and keep the point of clamping opposite the point of support in order to minimize distortion. If a milling fixture is necessary, it should be heavy enough to (1)

TABLE 5.—SPEEDS AND FEEDS

MATERIAL	SUGGESTED RANGE OF CUTTER PERIPHERAL CUTTING SPEEDS AND RECOMMENDED STARTING SPEEDS IN FEET PER MINUTE
Aluminum	500 to 3,000 maximum machining speed
Brass—hard and soft	800 to 1,000 900
Bronze:	
Tough	100 to 1,000 250
Soft	800 to 1,000 900
Cast iron:	
Soft gray	180 to 250 200
Medium gray	160 to 225 180
Hard gray	130 to 200 160
Steel content below 25 per cent	150 to 225 180
Steel content 25 to 40 per cent	160 to 300 200
Steel content over 40	180 to 350 220
Copper	300 to 1,000 maximum machining speed
Fiber	300 to 800 600
Malleable iron:	
Hard	150 to 225 180
Medium	160 to 300 200
Plastics	500 to 1,500 800
Steel:	
Carbon and alloy cast	Consult carbide supplier
Zinc alloy die castings	300 to 1,000 500

Suggested range of feeds expressed as feed per tooth and recommended starting feed per tooth in inches, as applied to face mills

Roughing	0.012 to 0.017 inch
Start	0.012 inch
One-pass finish	0.008 to 0.012 inch
Start	0.008 inch
Finishing	0.005 to 0.010 inch
Start	0.005 inch

absorb all the forces created by clamping and cutting without springing or deflecting the milling-machine table; (2) absorb the vibration developed by the cut. The construction of the milling fixture should allow for free flow of chips.

Cutting speed is dependent upon: (1) the design of the milling cutter; (2) the rigidity of the machine and its condition, and the power available; (3) the rigidity of the fixture, or the method of clamping the part; (4) the material from which the part is made and its hardness, the rigidity of the part and the amount of stock removed; and (5) the length of intervals desired between each resharpening of the cutter. Production requirements may make long intervals or short ones between grinds desirable. When a job is set up for given starting speeds and feeds it should also be run at speeds above and below these speeds and feeds to determine which gives the most economical production. A cutter run at the maximum economical speed tends to eliminate the built-up edge and thereby gives a freer cutting action.

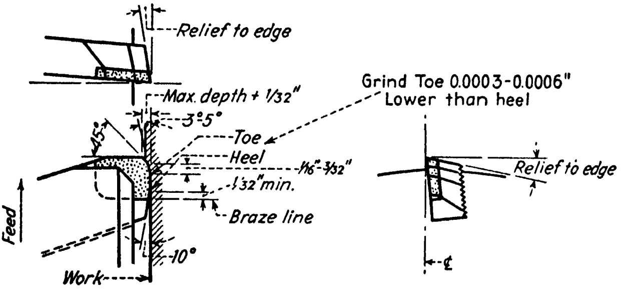


FIG. 5.—Face mills for close-limit work.

The proper rate of feed for milling a given piece of work with a cemented carbide-tipped milling cutter is dependent on several factors. Some of these are: (1) the machine used; (2) the power available—if all other conditions are satisfactory, the feed rate is limited only by the capacity of the motor; (3) design of the milling cutter; (4) the fixture used or rigidity in clamping; (5) the shape, rigidity, and hardness of the part being machined; (6) production rate—this should not be too low to give a light chip; (7) the degree of finish required, and (8) the depth of cut.

The logical method for determining the rate of feed in inches per minute for any milling cutter is to start from the feed-per-tooth basis. The feed per tooth multiplied by the number of tooth passages per minute (number of teeth in cutter times spindle feed in r.p.m.) will furnish the approximate starting feed in inches per minute to be set on the machine. This can be obtained without computation from Tables 4 and 5.

When a job is set up for a given starting feed which, it is estimated, will produce the desired degree of finish, it should also be run at feeds above and below the starting feed to determine which produces the most economical results.

Face mills that have a 15-degree chamfer on the corner of the teeth and run true on the face will produce a degree of finish that increases as the rate of feed decreases. When these face mills are ground with a 3- to 5-degree lead angle between the straight side, or face, and the 45-degree chamfer, the mill will produce the same degree of finish at an increased rate of feed, all other conditions remaining identical.

In Figs. 4 and 5 are shown two types of face-milling cutters. Figure 4 is a cutter for general-purpose milling, whereas Fig. 5 shows a cutter ground for special work requiring close limits.

The lead angle reduces the feed marks or revolution marks to a minimum. Decreasing the feed per tooth, or grinding a lead angle on the face of a cutter reduces the chip thickness, which in turn increases the abrasion at the cutting edge and decreases the cutter life. Always use the maximum feed possible that will give the desired finish on any milling operation.

The dulling of any cutter is dependent on the number of contacts a given tooth makes with the work. When an increased feed per tooth is used, all other conditions remaining the same, more material is removed for the same tooth wear.

Cemented-carbide-tipped milling cutters are capable of working in the surface scale of most castings practically as easily as the inner or softer material. In milling a scaly material, the increased feed per tooth will break up the scaly surface ahead of the cutting edge, so that the cutting edge will have reduced contact with the scaly surface. For this reason, it is necessary to allow only $\frac{1}{16}$- to $\frac{1}{8}$-inch stock for machining instead of following the older practice of allowing $\frac{1}{8}$ to $\frac{1}{4}$ inch. This may often permit the use of a one-pass finish (rough and finish cut combined).

Mounting the Cutter on the Spindle Nose.—The satisfactory performance of any face mill is dependent on its proper mounting on the machine spindle or arbor. This mounting should be the same as that used for sharpening and inspection. Whenever possible it should be fastened directly to the spindle nose either by bolts or by a nut arbor. The face of the spindle nose should be flat, smooth, and free from nicks and burrs. Any portion of either the machine spindle or centering plug or arbor supporting the face mill that in any way comes in actual contact with the face mill should run true. No other portion of the machine spindle, centering plug, or arbor should have rigid contact with the face mill in any way. The necessary keys for driving, and the bolts, nuts, or screws used for clamping, should have only a slidable or self-adjusting contact with the face mill, so that they will in no way bind and force the face of the mill to run out. (See Figs. 6 to 9 for details.)

Production milling data accumulated to date from milling with cemented carbide-tipped face mills indicate that, when it is necessary to use a coolant, a solution of soluble oil offers the best results. A soluble oil solution carries away the heat two to three times as fast as the usual cutting oils.

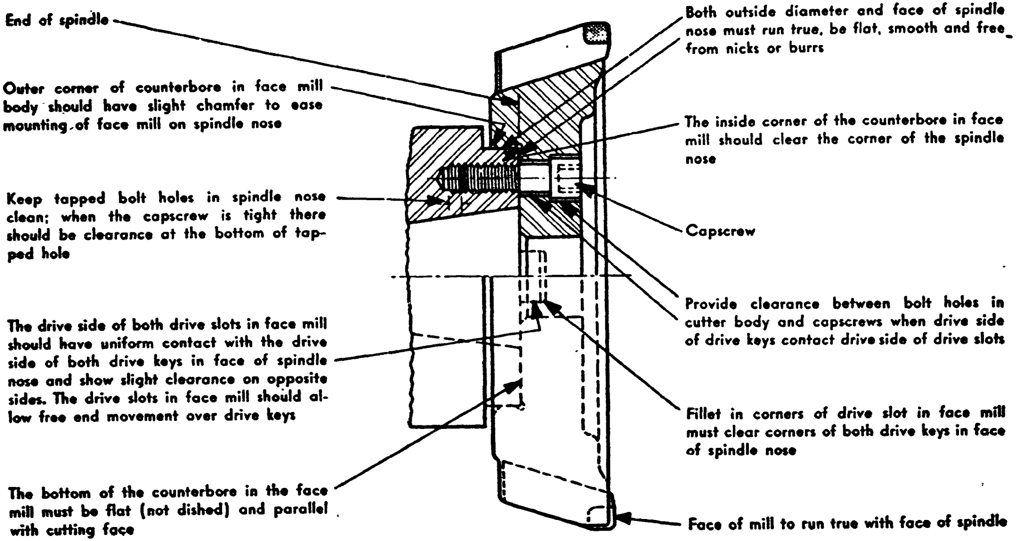

End of spindle
Outer corner of counterbore in face mill body should have slight chamfer to ease mounting of face mill on spindle nose
Keep tapped bolt holes in spindle nose clean; when the capscrew is tight there should be clearance at the bottom of tapped hole
The drive side of both drive slots in face mill should have uniform contact with the drive side of both drive keys in face of spindle nose and show slight clearance on opposite sides. The drive slots in face mill should allow free end movement over drive keys
The bottom of the counterbore in the face mill must be flat (not dished) and parallel with cutting face
Both outside diameter and face of spindle nose must run true, be flat, smooth and free from nicks or burrs
The inside corner of the counterbore in face mill should clear the corner of the spindle nose
Capscrew
Provide clearance between bolt holes in cutter body and capscrews when drive side of drive keys contact drive side of drive slots
Fillet in corners of drive slot in face mill must clear corners of both drive keys in face of spindle nose
Face of mill to run true with face of spindle

FIG. 6.—Face mill centered by outer diameter of spindle.

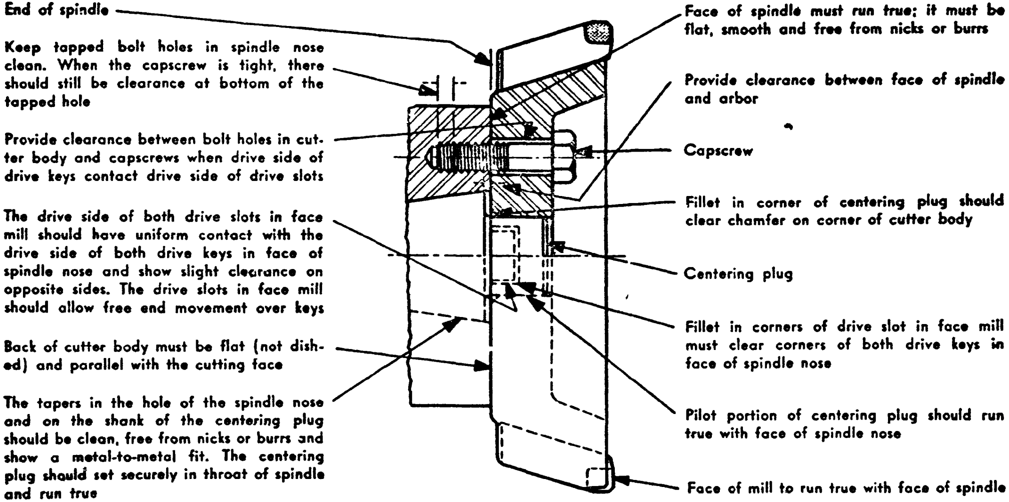
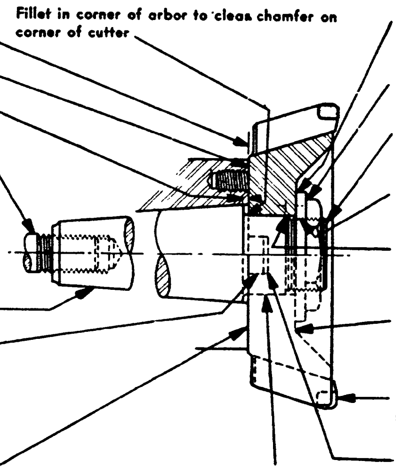

End of spindle
Keep tapped bolt holes in spindle nose clean. When the capscrew is tight, there should still be clearance at bottom of the tapped hole
Provide clearance between bolt holes in cutter body and capscrews when drive side of drive keys contact drive side of drive slots
The drive side of both drive slots in face mill should have uniform contact with the drive side of both drive keys in face of spindle nose and show slight clearance on opposite sides. The drive slots in face mill should allow free end movement over keys
Back of cutter body must be flat (not dished) and parallel with the cutting face
The tapers in the hole of the spindle nose and on the shank of the centering plug should be clean, free from nicks or burrs and show a metal-to-metal fit. The centering plug should set securely in throat of spindle and run true
Face of spindle must run true; it must be flat, smooth and free from nicks or burrs
Provide clearance between face of spindle and arbor
Capscrew
Fillet in corner of centering plug should clear chamfer on corner of cutter body
Centering plug
Fillet in corners of drive slot in face mill must clear corners of both drive keys in face of spindle nose
Pilot portion of centering plug should run true with face of spindle nose
Face of mill to run true with face of spindle

FIG. 7.—Face mill centered by plug in spindle.



End of spindle

Face of spindle nose must run true; it must be flat, smooth and free from nicks or burrs

Clearance between face of spindle and arbor

Draw-in bolt must be tight

Both the taper in the hole of he spindle nose and on the shank of the centering arbor should be clean, free from nicks or burrs, and show a metal-to-metal fit for mating length. The centering arbor should set itself securely in throat of spindle, and run true

The drive side of both drive slots in face mill should have uniform contact with the drive side of both drive keys in face of spindle nose and show slight clearance on opposite sides. The drive slots in face mill should allow free end movement over the drive keys

Back of cutter body must be flat (not dished) and parallel with cutting face

Fillet in corner of arbor to clear chamfer on corner of cutter

Pilot portion of arbor should run true with face of spindle nose

Arbor nut

There should be clearance between pilot portion of arbor and nut

Centering arbor

Threads on screw to have loose fit in threads of nut to allow cutter to run true

Fillet in corner of arbor to clear chamfer in tapped hole in nut

Bottom of counterbore in face mill to run true with both its back and hole after clamping

Face of mill to run true with face of spindle nose

Fillet in corners of drive slot in face mill must clear corners of both drive keys in face of spindle nose

FIG. 8.—Face mill centered by arbor.

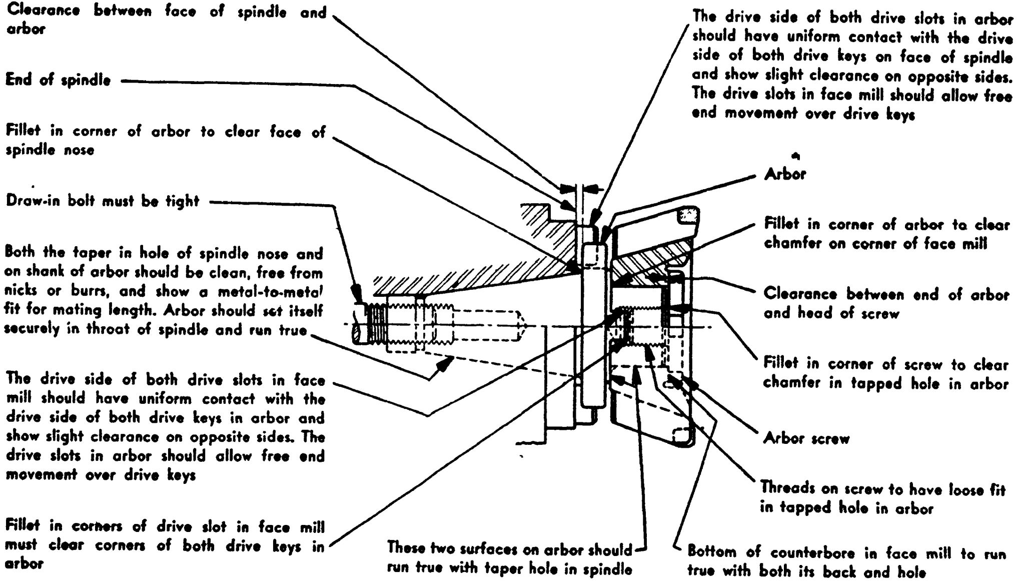

Clearance between face of spindle and arbor
End of spindle
Fillet in corner of arbor to clear face of spindle nose
Draw-in bolt must be tight
Both the taper in hole of spindle nose and on shank of arbor should be clean, free from nicks or burrs, and show a metal-to-metal fit for mating length. Arbor should set itself securely in throat of spindle and run true
The drive side of both drive slots in face mill should have uniform contact with the drive side of both drive keys in arbor and show slight clearance on opposite sides. The drive slots in arbor should allow free end movement over drive keys
Fillet in corners of drive slot in face mill must clear corners of both drive keys in arbor
These two surfaces on arbor should run true with taper hole in spindle
Bottom of counterbore in face mill to run true with both its back and hole
The drive side of both drive slots in arbor should have uniform contact with the drive side of both drive keys on face of spindle and show slight clearance on opposite sides. The drive slots in face mill should allow free end movement over drive keys
Arbor
Fillet in corner of arbor to clear chamfer on corner of face mill
Clearance between end of arbor and head of screw
Fillet in corner of screw to clear chamfer in tapped hole in arbor
Arbor screw
Threads on screw to have loose fit in tapped hole in arbor

FIG. 9.—Face mill adapted to taper hole in spindle.

On most face-milling operations where it is necessary to use a coolant, it should be a flood and not a trickle. A slight flow of coolant is detrimental to cemented carbide and results in cutter failure. Proper splash guards should be provided to protect the operator. A single stream of coolant as in Fig. 10 is never satisfactory.

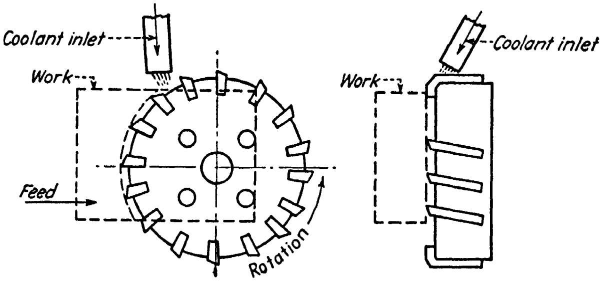


FIG. 10.—A single stream of coolant sometimes leads to trouble.

On wide cuts, a nozzle having a semicircular shape located roughly as shown in Fig. 11 is suggested. The inner circumferential portion of the nozzle has large drilled holes or elongated slots angularly positioned to direct the flow of coolant at high velocity against the cutting teeth. This keeps all cutting teeth cool and holds the machine's down time to a minimum. The nozzle should be posi-

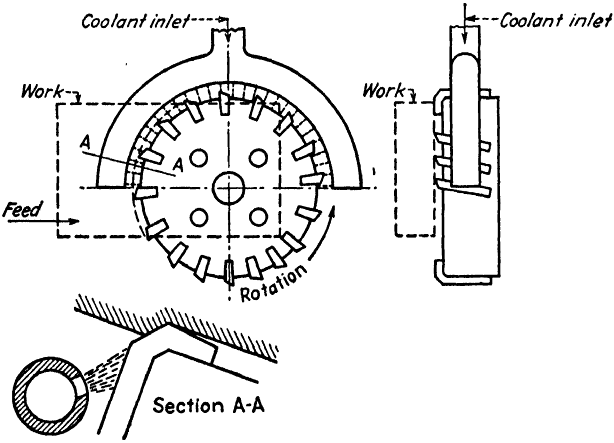


FIG. 11.—Semicircular nozzles keep face-mill teeth cool.

tioned so as not to interfere with the flow of chips away from the work.

Two methods of mounting cutters on the face of the spindle are shown in Figs. 6 and 7. In Fig. 6 the cutter is centered by the outer diameter of the spindle nose, and in Fig. 7 the cutter is centered by a plug held in the taper of the spindle. In either case the face of the milling cutter must run true with the face of the spindle. Both methods use capscrews to hold the cutter against the face of the spindle.

Two other methods are shown in Figs. 8 and 9. In Fig. 8 the cutter is centered by the nose of the taper arbor; this is held in the spindle by the draw-in bolt, which must be tight. Here the cutter seats against the face of the spindle.

In Fig. 9 an arbor having a collar is used, this acting as an adapter between the milling cutter and the milling-machine spindle. In both cases the actual driving of the cutter is done by the keys on the face of the spindle, which should have uniform contact with both drive key slots in the milling cutter or in the collar of the arbor, as in Fig. 10.

Causes and Elimination of Chatter.—Chatter may be caused by improper sharpening. It can sometimes be eliminated by reducing the cutting relief angles. In other cases the motor on the machine may be working beyond its normal capacity, so that the flow of power fluctuates.

Another cause of chatter is too much contact between the cutting edge of the teeth on the cutter and the surface of the work. In these cases chatter frequently can be reduced by resharpening. Varying the size and angle of chamfer may correct it.

The work may not be clamped firmly. If the part includes thin sections, more support is required behind such sections to prevent vibration. Chatter may be caused by too light a fixture, or by loose gibs in the knee of the miller.

Increasing the rate of feed will often eliminate chatter. Often a flywheel mounted on the cutter spindle will neutralize chatter or the use of braces connected to the overarm may eliminate it.

A dull cutter should never be used, because it consumes increasingly more power, leaves an inferior finish, and may destroy the accuracy of the part being machined. It is false economy to allow the cutter to become dull to such an extent that a heavy grind is necessary, for more time is required to sharpen a very dull than a slightly dull cutter, and valuable carbide is wasted.

It is an economy to remove the cutter for sharpening as soon as the cutting edges become slightly rounded and leave a poor finish. Many plants determine some definite number of hours' run for the cutter before it becomes extremely dull, and then remove it for sharpening. Machine down time can be held to a minimum if this change period comes at the time of a shift change.

BROACHES

Tooth shape and smoothness are two essentials of good broaching. Except for broaches used in cored holes, wear should not

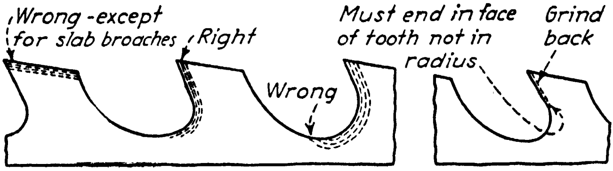
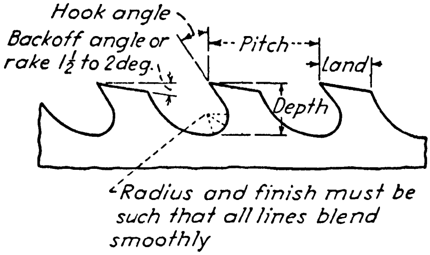

Wrong - except for slab broaches
Right
Wrong
Must end in face of tooth not in radius
Grind back

FIG. 12.—Methods of sharpening broach teeth.

TABLE 6.—DIMENSIONS FOR ROUND AND SPLINE BROACHES


Hook angle
Backoff angle or rake $1\frac{1}{2}$ to 2 deg.
Pitch
Land
Depth
Radius and finish must be such that all lines blend smoothly

Cut Length	Pitch	Land	Depth	Radius
$\frac{3}{16}$	$\frac{1}{8}$	$\frac{3}{64}$	$\frac{3}{64}$	$\frac{1}{32}$
$\frac{1}{4}$	$\frac{3}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{32}$
$\frac{3}{8}$	$\frac{7}{32}$	$\frac{1}{16}$	$\frac{5}{64}$	$\frac{3}{64}$
$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{16}$	$\frac{3}{32}$	$\frac{1}{16}$
$\frac{3}{4}$	$\frac{5}{16}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{5}{64}$
1	$\frac{11}{32}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{5}{64}$
$1\frac{1}{8}$	$\frac{3}{8}$	$\frac{7}{64}$	$\frac{9}{64}$	$\frac{3}{32}$
$1\frac{1}{4}$ to $1\frac{5}{8}$	$\frac{7}{16}$	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{7}{64}$
$1\frac{3}{4}$ to 2	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{8}$
$2\frac{1}{4}$ to $2\frac{1}{2}$	$\frac{9}{16}$	$\frac{9}{64}$	$\frac{7}{32}$	$\frac{9}{64}$
$2\frac{3}{4}$ to $3\frac{1}{4}$	$\frac{5}{8}$	$\frac{5}{32}$	$\frac{15}{64}$	$\frac{5}{32}$
$3\frac{1}{2}$ to 4	$\frac{11}{16}$	$\frac{5}{32}$	$\frac{9}{32}$	$\frac{3}{16}$
$4\frac{1}{4}$ to $4\frac{3}{4}$	$\frac{3}{4}$	$\frac{5}{32}$	$\frac{19}{64}$	$\frac{3}{16}$
5 to $5\frac{1}{2}$	$\frac{13}{16}$	$\frac{5}{32}$	$\frac{5}{16}$	$\frac{13}{64}$
$5\frac{3}{4}$ to 6	$\frac{7}{8}$	$\frac{3}{16}$	$\frac{11}{32}$	$\frac{7}{32}$
$6\frac{1}{2}$ to 7	$\frac{15}{16}$	$\frac{3}{16}$	$\frac{23}{64}$	$\frac{7}{32}$
$7\frac{1}{2}$ to 8	1	$\frac{7}{32}$	$\frac{3}{8}$	$\frac{1}{4}$
$8\frac{1}{2}$ to $10\frac{1}{2}$	$1\frac{1}{8}$	$\frac{1}{4}$	$\frac{25}{64}$	$\frac{1}{4}$
11 to 12	$1\frac{1}{4}$	$\frac{9}{32}$	$\frac{13}{32}$	$\frac{7}{64}$

exceed 0.005 inch before resharpening. Hook angle is important but on small broaches depends somewhat on the grinding wheels that can be used.

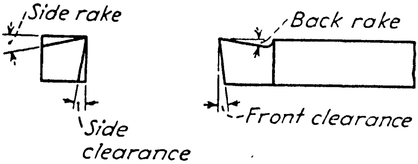
Hook angles increase with the ductility of the material. Suggested hook angles are: cast iron, 6 to 8 degrees; hard steel, 10 degrees; soft steel, 15 degrees; aluminum 15 degrees or more; brittle brasses and bronzes, no hook to minus 5 degrees.

The manner of grinding is also important. The original hook angle should be maintained and the depth of the space should not be increased. The illustrations explain themselves. When the grind is confined to the upper part of the tooth, as in Fig. 12, it acts as a chip breaker. Grinding should be on the face of the tooth except for broaches that slab, or finish outside surfaces, for this does not affect size. For this work the rake is sometimes increased to 3½ degrees.

General dimensions for round and spline broaches are given in Table 6.

TURRET LATHE TOOLS

TABLE 7.—SUGGESTED CUTTER ANGLES FOR TURRET LATHE WORK (In Degrees)



Material	Side Clearance	Front Clearance	Back Rake	Side Rake
Cast iron	8	8	5	12
Copper	12	10	20	25
Brass	10	8	0	0
Hard bronze	8	8	0	0 to 2
Aluminum	10	8	35	15
S.A.E. 1315	10	8	15	20
S.A.E. 1045	8	8	12	15
S.A.E. 2315	8	8	12	15
S.A.E. 3140	8	8	10	12
S.A.E. 3250	8	8	8	12
S.A.E. 4140	8	8	12	15
S.A.E. 6145	8	8	8	12
Stainless steel	10	8	15	10

Warner and Swasey.

Cutting Angles for Turret Lathe Tools.—Table 7 gives suggested cutter angles for turret lathe tools for machining cast iron, steels, and nonferrous metals. The table covers angles for side clearance, front clearance, and back and side rakes.

USING CARBIDES ON OLDER MACHINE TOOLS

Cutting Speeds.—It is stated by authorities that there is no reason why older types of machines in good condition—such as boring mills and turret lathes—cannot be adapted readily to the use of carbide tooling. The main consideration in old equipment, as well as in the new types of machine tools, is that the machine must be able to run fast enough—and smoothly enough at that faster speed.

The main objective to keep in mind in cutting steels with carbides is that the cutting speed be high enough to prevent the forming of a "built-up" edge. This means an average cutting speed in the neighborhood of 200 feet per minute (the lower the carbon, usually, the higher the speed).

Checking Old Machines.—The adaptability of an available tool to the use of carbides can be checked by the following considerations:

It takes more power to run at the higher speeds required—to remove metal at a faster rate. It takes more power, also, to cut steel than to cut nonferrous metals or cast iron. Horsepower requirements may be calculated by the following formula:

H.P. per tool = depth of cut in inches × feed in inches × (surface feet per minute) × (power constant).

The power constant varies from 6 to 10, depending on the steel to be cut, as follows:

Steel	Constant	Steel	Constant
1010 to 1025	6	3115 to 3130	8
1030 to 1095	8	3135 to 3450	9
1112 to 1120	6	4130 to 4820	9
X1314 to X1340	8	5120 to 52100	10
T1330 to T1350	9	6115 to 6195	10
2015 to 2320	7	Cast steel	9
2330 to 2350	9		

The power required to operate the machine at speed with tools not cutting must be added, of course, to obtain motor horsepower. This requirement is usually figured as 30 per cent of the horsepower required for cutting.

Then belts, clutches, etc., should be checked for ability to transmit the horsepower to the spindle. Clutch fingers should be adjusted to prevent slipping and stalling. When the machine is equipped with a flat belt, it may be changed to a V belt drive, making sure that the number of belts is adequate.

Note: If the machine stalls in the cut, loosen the holding screws and remove the tool from the cut to prevent breakage. Do not attempt to move the work or try to back the tool out of the cut.

The high speeds make it advisable to use an antifriction tailstock center. Spindles should be checked for adequate lubrication at the higher speeds at which they will operate. Solid supports should be used under the tools in place of rocker tool plates, and shims should be used to keep the tool at proper cutting height.

To handle the increased volume of chips, where openings in machine bands and around tool blocks are small, sheet-metal chutes are useful to prevent chips from clogging slots and pockets; and chip breakers can be used where size of openings require production of small chips.

Excessive tool clearances that might cause chatter at the higher cutting speeds and worn bearings, slides, and ways should be corrected. Where it is impractical to tighten the machine up sufficiently to eliminate all chatter, a certain amount can be corrected by the use of negative rakes in the tools.

COOLANTS FOR CARBIDE TOOLS

Usually, increased cutting fluid capacity and flow are required when machining with carbide-tipped tools, because of the very high speeds at which machines can and should be operated when cutting with such tools. Not only should the pump have sufficient capacity to supply large volumes of the fluid under sufficient pressure to cool the tool and work adequately, but the cutting fluid must be so directed that it will not be carried away from the tool by the fast-moving chip. Several ways of directing the fluid are shown in Fig. 13.

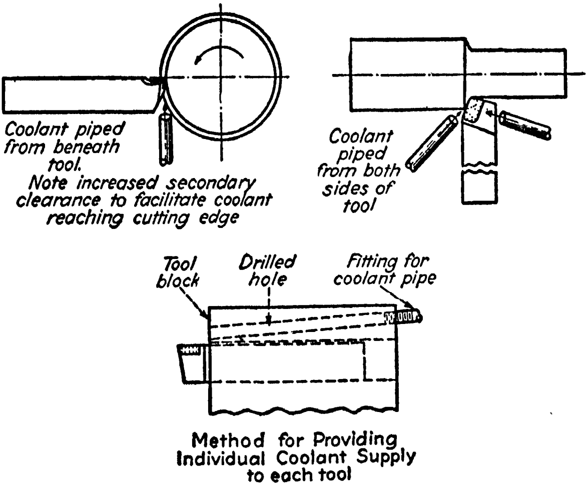

Coolant piped from beneath tool.
Note increased secondary clearance to facilitate coolant reaching cutting edge
Coolant piped from both sides of tool
Tool block
Drilled hole
Fitting for coolant pipe
Method for Providing Individual Coolant Supply to each tool

FIG. 13.—Using coolants on carbide tools.

The prime requisite of a cutting fluid for use with carbide-tipped tools is cooling quality. A good soluble oil works well. Cutting oils are used but in some cases are objectionable because of the smoke developed. It is reported that straight cutting oils are not good coolants at speeds in excess of 200 surface feet per minute; however, where chip pressures are high and lubricating qualities of oils are desirable, large volumes can be used to enhance cooling.

SMALL END MILLS

Speeds.—The growing use of the small high-speed heads for milling machines makes it necessary to use sufficient speed if best results are to be obtained. Table 8 gives what Kearney & Trecker call the Weldon chart to be used with the high-speed attachment made for their machines.

TABLE 8.—THE WELDON CHART OF APPROXIMATE SPEEDS FOR END MILLS

Diameter of End Mill, in Inches	Tool Steel 70 Ft. per Min., R.p.m.	Machine Steel 80 Ft. per Min., R.p.m.	Cast Iron 90 Ft. per Min., R.p.m.
1/16	4,276	4,888	5,498
3/32	2,855	3,259	3,688
1/8	2,140	2,440	2,750
3/16	1,420	1,625	1,830
1/4	1,070	1,222	1,375
5/16	856	978	1,100
3/8	713	815	917
7/16	611	698	786
1/2	535	611	688
9/16	475	543	611
5/8	428	489	550
11/16	389	444	500
3/4	357	407	458

CUTTING LIQUIDS

From 3 to 5 gallons of cutting liquid per minute should be supplied to each single point tool. Some report that sulphurized oils are detrimental to carbide tools. On complicated machines such as automatics and gear cutters a rich emulsion, using only 10 parts of water instead of the usual 20 to 40 parts, is recommended.

SECTION V

GRINDING-WHEEL MARKINGS

The desirability of a uniform system for marking grinding wheels has long been recognized. On several occasions such systems have been given actual trials in selected groups of consumer plants. The last attempt showed promise. After a year's trial it was submitted and subsequently approved under American Standards Association procedure as an American Standard (B5.17—1943). Satisfactory reports from the limited number of plants in which it was tried proved premature, as in extending its use to other plants reactions were brought out indicating shortcomings.

The committee of the Grinding Wheel Manufacturers Association is of the opinion that the principal reasons for the failure of the American Standard were that confusion existed because it was not made clear that wheels similarly marked, if made by different manufacturers, would not grind alike.

However, the grinding wheel manufacturers are agreed that much good can be accomplished by use of a uniform system of markings, provided the limitations of the system are clearly understood. The standard, submitted herewith, is a *standard of markings only* and not of grinding action. The most important revision was the adoption of an alphabetical marking system, for all bond types, to designate grade of hardness. Better provision was made for the wheel maker to incorporate into the marking such special symbols as might be required to properly qualify the basic symbols of the standard markings.

Members of the Grinding Wheel Manufacturers Association have voted to adopt this system. The individual members will start putting it into effect as soon as expedient, but months may be required to make the transition complete. During this period and perhaps for a considerable time thereafter, wheels may be marked with both the new standard and the wheel maker's own marking. This is referred to in the standard as "dual marking." It is intended that the Dual System will eventually be abandoned and that the new Standard Marking alone will be found to be adequate.

This was submitted to all grinding wheel consumers as a Grinding Wheel Manufacturers Association standard, March 16, 1944.

PURPOSE AND SCOPE

This standard applies to grinding wheels and other bonded abrasives: segments, bricks, sticks, hones, rubs, and other shapes, which are tools used to remove material, alter shape or size, produce a desired surface or accuracy of dimension, or a combination of these objectives.

The standard does not apply to diamond wheels or to specialties such as sharpening stones where radically different symbols are commonly used.

The Standard establishes a symbol for each of the most essential characteristics of a grinding wheel, and arranges these symbols in uniform sequence.

This is a standard *system of markings only*. Wheels bearing the same standard markings if made by different wheel manufacturers may not and probably will not produce the same grinding action. This desirable result cannot be accomplished because of the impossibility of correlating any measurable physical properties of bonded abrasive products in terms of their grinding action.

Sequence of Markings.—Each marking will consist of six parts, placed in the following sequence:

1. Abrasive type.
2. Grain size.
3. Grade.
4. Structure.
5. Bond type.
6. Manufacturer's record.

1. *Abrasive.*—Abrasives naturally fall into two distinct groups, namely the aluminum oxide group and the silicon carbide group. Letter symbols are used to identify these two groups, as follows:

A	Aluminum oxide.
C	Silicon carbide.

Where it is necessary to designate some particular type of these broad classes, the manufacturer may use his own symbol or brand designation as a prefix.

2. *Grain Size.*—Grain size is indicated by a number.

The following list (from coarse to fine) includes all of the ordinary grain sizes commonly used in the manufacture of grinding wheels.

10, 12, 14, 16, 20, 24, 30, 36, 46, 54,
60, 70, 80, 90, 100, 120, 150, 180, 220

The following additional sizes are occasionally used: 240, 280, 320, 400, 500, 600.

If and where it is necessary to indicate a special grain combination, the wheel maker may use an additional symbol appended to the regular grain symbol.

3. *Grade.*—The grade is indicated by a letter of the alphabet, A to Z, soft to hard, in all bonds or processes.

4. *Structure.*—The use of a structure symbol is optional. If and where it is advisable to indicate the structure in a wheel marking, a simple number symbol shall be used. Numbers from 1 to 15 will cover the range of structures being used today, but there is no reason why higher numbers cannot be used if necessary. Progressively higher numbers are used to indicate progressively wider grain spacing (sometimes called "more open" structure).

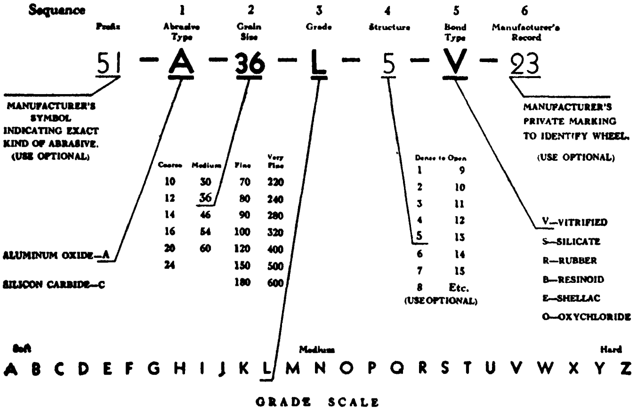
5. *Bond or Process.*—The bond or process is designated by the following letters:

V	Vitrified.
S	Silicate.
E	Shellac or elastic.
R	Rubber.
B	Resinoid (synthetic resins).
O	Oxychloride.

6. *Manufacturer's Record.*—Manufacturer's records are designated by symbols. Each grinding wheel manufacturer is at liberty to use the sixth position for private factory records.

Dual Marking.—Where the standard method of marking differs materially from the old form, it may be advisable to use both the old and the new markings during the introductory period, and perhaps for a considerable time thereafter. This would enable the user to become accustomed to the conversion gradually.

STANDARD MARKING SYSTEM CHART



Where wheels are too small to permit the use of the complete marking, the grain and grade marking alone may be used on the wheel, or the marking on the wheel itself may be omitted entirely. Where this is done, the complete marking (including the dual marking where necessary) shall be indicated on tags or labels accompanying each container.

Wheel Manufacturer's Name.—Because of the greater similarity in marking that will result in many cases from the use of this system, it is important that the user include in his records the name of the wheel maker as a part of the marking.

ABRASIVE CUTTING

Special Wheels.—Abrasive wheels for cutting should be made especially for their work. For dry cutting the Andrew C. Campbell

Division of the American Chain and Cable Company recommend a surface speed of 15,000 feet per minute as being twice as effective as a speed of 9,000 feet per minute. For wet cutting 8,000 feet per minute is about the limit if coolant is to be retained on the wheel in sufficient quantities to be effective. Efficiency of a wet wheel drops much less with speed reduction than a dry wheel.

Use only wheels made especially for the type of cutting-off machine for which they were designed. It is just as much an engineering problem to design and make a wheel for a special job as it is to design and make a milling cutter.

Estimates as to cutting time may be made on the basis of 6 seconds cutting time per square inch of material up to sizes of 3 square inches. Larger sizes require somewhat more time. Wheel costs can be estimated as from 0.003 to 0.005 cent per square inch up to 3 square inches and from that up to 0.007 cent per square inch on larger sizes. These estimates apply particularly to the types of machine built by the American Chain and Cable Company.

Abrasive Saws or Cutting-Off Wheels.—Abrasive wheels used as saws for cutting metal or other rods or tubes are usually from 10 to 18 inches in diameter. Some, made for slitting pen nibs, are only 0.005 inch thick. Regular thicknesses are $\frac{1}{16}$, $\frac{1}{8}$, and $\frac{3}{32}$ inch.

GRINDING WHEELS

Care of Grinding Wheels.—It should be remembered that *truing* and *dressing* are entirely different. A new wheel must be *trued* after it is mounted on its spindle and should stay true until worn out.

Wheels should be *dressed* as soon as the grains of abrasives in the face of the wheel become dull. The diamond wheel dresser cuts away the dulled grains and presents a new sharp cutting surface.

Before dressing, as before grinding, the machine should be warmed up by running it for 10 minutes or more. With a cold machine the oil films are not complete and the parts have not expanded to running temperature.

When truing a new wheel, or a badly worn wheel, start the diamond cutting at the center and work both ways until the face is true. If the cut starts at a worn corner it throws too much work on the diamond when it gets to the center.

The diamond must be rigidly supported and should be turned frequently to present new sharp points to the wheel. A large diamond will absorb more heat than a small one and should be used where possible.

The diamond should meet the wheel at a slight angle. For a high finish on the work, pass the diamond across the face slowly. For rapid stock removal, move the diamond across the wheel face at a good rate.

Use plenty of coolant while the diamond is in use. It will prevent fractures in the diamond from overheating. Reset the diamond after it is worn excessively, or if the setting is accidentally ground away.

Diamonds leave marks on the face of the wheels. These are often reproduced in grinding soft metal. For a high finish on aluminum and magnesium, use a mechanical wheel dresser.

Grinding.—The rate of travel of the work past the wheel affects the finish. For rough grinding the work can travel nearly the width of the wheel face at each revolution.

For ordinary finishing the travel of the work carriage should not exceed ½ inch for each revolution of the wheel. To secure the extra-fine mirror finish the work speed may have to be reduced as low as ⅛ inch for each revolution of the work.

Variation in materials and general characteristics of the work prevent the laying down of any fixed rules as to work-carriage speeds. If the travels suggested do not give desired results, it will be necessary to experiment with variations in both directions.

Work Speeds.—No hard and fast rules for work speeds can be given. For average conditions the work speed will range from 60 to 100 surface feet per minute. Some suggested variations follow.

Kind of Work	Work Speed, in Feet per Minute
Unbalanced work, such as crankshafts	35 to 45
Irregular shapes, such as camshafts	
Roughing	30
Finishing	15
Aluminum, such as pistons	100 to 200

Work speed can also be varied to secure different wheel effects. If the only wheel available is softer than desired, a slower work speed tends to give it the effect of being harder. A higher work speed gives a hard wheel the effect of being softer.

High work speed and low traverse speed allow a greater depth of cut.

Work speed is particularly important when formed wheels are used. This is because comparatively small variations in wheel diameter cause great variations in the speed of the different portions of the wheel. The best that can be done is to consider the wheel speed at the average diameter of the wheel and select the work speed accordingly. The foregoing suggestions are made by the Landis Tool Company.

Wheels for Thread Grinding.—The growth of thread grinding makes the use of the best wheels an important item. According to A. Rosseau of the Norton Company, vitrified wheels should be used where the tolerances are close on either form or lead. This includes gages, lead screws, and precision taps. They should also be used for worms where several light cuts are taken and for internal thread grinding.

Resinoid-bonded wheels are recommended for high-production jobs or where the work must be finished with the fewest possible cuts but where extreme accuracy is not required.

Grit is controlled largely by the pitch of the thread to be ground. Table 4 shows the wheels suggested, based on the width of the root of the thread, which is the determining factor. The material being ground may help determine the grit to be selected. High-speed and other hard steels seem to grind better with finer grit wheels, even where the threads are relatively coarse. Lower wheel speeds are advised on these hard steels and where a fine finish is important. Light feeds and high work speed call for finer and harder wheels than heavy feeds and slow work speeds.

On tough steels slow work speeds and few passes are usually best. On such material 10- or 12-pitch threads are ground in two passes, and at times in a single pass with a work speed of 1½ to 2 feet per minute. Screws of 18 pitch and finer are often ground at a single pass.

Both vitrified and resinoid wheels are being operated at speeds from 6,500 to 12,000 surface feet per minute. High speed seems to make a fine-grit wheel remove stock faster. Safety must always be considered, and no wheel should be run faster than the maker's recommendations.

TABLE 1.—RELATIONSHIP OF GRIT SIZE TO ROOT WIDTH

Root Width, in Inches	Grit Size	
	Vitrified Wheels	Resinoid Wheels
0.003	220	180
0.004	180	150
0.005	150	120
0.006	120	120
0.007	120	100
0.008	100	100
0.009	100	90
0.010	90	90

SECTION VI

GEARING

BEVEL GEARS

A recent development in bevel gearing is the Zerol gear tooth of the Gleason Works. This is a curved tooth with no spiral angle. This gives the advantages of a continuous contact and avoids concentrated loads on the ends of the teeth in case of slight misalignment. This is shown in Fig. 1.

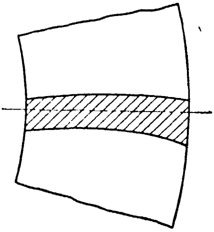


FIG. 1.—Zerol tooth form.

The Gleason Works have also developed the Formate gear tooth as a feature of the spiral-gear system. With the Formate tooth form only the cutter moves, the gear blank remaining stationary during the cutting of each tooth. The mating pinion or gear, however, is cut in a regular spiral-gear generating machine to match the Formate tooth.

Machines are now available for grinding the teeth of spiral bevel gears after hardening. The generating method differs from that formerly used, combining a continuous rotation of the work spindle with a reciprocating motion of the cradle that carries the grinding wheel.

ANGLE OF WORM THREADS AND HELICAL GEAR TEETH

Terminology.—Confusion sometimes arises from different interpretations of the term "thread angle." This was formerly considered as the angle between the thread and a line at a right angle to the axis of the worm. The present practice is to use the term "helix angle" for this measurement.

By the old method the worm would be said to have a thread angle of 3 degrees, while present practice refers to it as having a helix angle of 87 degrees.

Confusion is also caused by the use of both *helical* and *spiral* for gears with teeth not parallel with the axis. As the only spiral is a clock spring or scroll, the use of *helical* is correct. Those who still use the term "spiral" refer to the angle as a "spiral angle" and so cause some confusion because we use "helix angle" for the same measurement.

Helical gears usually have a helix angle of less than 45 degrees. Single-thread worms may have a helix angle as high as 85 degrees.

Calculations are therefore frequently based on the *complement* of the angle instead of using the large value of the angle itself, for it is easier to handle in calculations. In this case we use the term "lead angle" instead of helix angle. This is used frequently in connection with worm gears.

In screw-thread practice however, the helix angle is the angle between the thread and a line at right angles to the axis of the screw. Thread angle in this case is the angle between the sides of the thread. It is unfortunate that the same terms are not used for the same geometric values in both gear and thread practices.

HOURGLASS WORMS

The hourglass type of worm is a very old idea. It was probably first used in this country in the 1890's by the Albro-Clemm Elevator and was known as the "Hindley" worm. It was cut in a lathe by a tool, or tools, held in a cutter head that represented the worm wheel. The tool head revolved as the worm turned and cut the thread on the worm to match the contour of the worm wheel with which it was to run. In its first form, this type of worm caused considerable controversy but made little headway. Somewhat similar methods were used by the Rock Island Arsenal in the early 1900's.

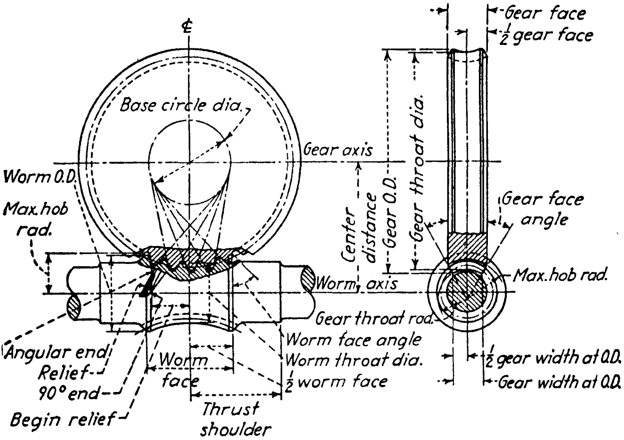


FIG. 2.—Cone worm and wheel.

The present hourglass worm, known as the "Cone," is cut with rotating cutters in a special machine built by the Michigan Tool Company. The worm wheels are cut with hobs of the hourglass form. A typical layout for a Cone worm and gear is shown in Fig. 2. The recommended backlash and tolerances for center distance, gear side position, and worm end position, are shown in Table 1.

Cone Gear Tolerances.—Cone gears are not more sensitive to misalignment than conventional worm gearing. Any center-distance assembly errors affect the capacity and efficiency of Cone drive gears to the same extent that they affect conventional worm gearing. Since the gears of both types are throated, it is necessary to hold their side positions within reasonable limits. And since the Cone worm is also throated, it must similarly be held within the same reasonable limits as for the gears of either type. However, Cone drives have the advantage that both worm and gear are regenerative and therefore tend to correct themselves if assembled in a misaligned position.

TABLE 1.—RECOMMENDED BACKLASH OF CONE GEARS

Center Distance	Standard Backlash	Number of Teeth in Gear
3.000	0.003 to 0.005	24 to 30
4.000	0.004 to 0.006	25 to 31
5.000	0.005 to 0.007	27 to 33
6.000	0.006 to 0.008	28 to 35
8.000	0.008 to 0.010	29 to 37
10.000	0.010 to 0.015	30 to 40
12.000	0.015 to 0.020	32 to 45
13.500	0.015 to 0.020	36 to 52
15.000	0.015 to 0.020	40 to 55
18.000	0.020 to 0.025	43 to 60
20.000	0.020 to 0.025	45 to 66
22.000	0.025 to 0.030	48 to 70

TOLERANCES FOR CENTER DISTANCE, GEAR SIDE POSITION, AND WORM END POSITION

Center distances up to 6 inches..........	+0.001 or −0.001 inch
Center distances from 6 to 15 inches.....	+0.002 or −0.002 inch
Center distances more than 15 inches.....	+0.003 or −0.003 inch

The side position of the gear and end position of worm should be held to the same tolerances as for center distance.

All Cone drives are cut on accurate adapters that are ground to close limits. The blueprint dimension for center distance, side position of gear, and end position of worm may therefore be regarded as exactly correct.

GEARS

Gear-Tooth Clearances.—Gear-tooth clearances in fine-pitch gears are important if backlash in fine mechanisms is to be prevented. The American Gear Manufacturers Association recommends the following formula for gears having very fine teeth. The formula is

$$\text{Clearance} = \frac{0.200 \text{ inch}}{\text{diametral pitch}} + 0.002 \text{ inch.}$$

This makes the desired clearance for a gear having 40 diametral pitch, 0.200 divided by 40 = 0.005. Adding 0.002 gives 0.007 inch.

GEAR MEASUREMENT BY WIRES

The H. L. Van Keuren Co. have prepared the following tables for use with suitable measuring wires. These are based on formulae by Earl Buckingham and approved by the American Gear Manufacturers Association. The tables were computed by Dr. C. H. Havill of Eclipse Aviation Co. and are believed to be more accurate than any previously available. Wire sizes are given in Table 2. Tables 3, 4, 5, and 6 need no explanation. Table 7 gives new values for some of the parts of Fellows stub teeth.

EXAMPLES.—An even-toothed external gear of 26 teeth, 12 diametral pitch, 14½-degree pressure angle is measured with 0.144 inch diameter wires. From Table 3 the measurement for 1 D.P. is 28.4315 inches. For 12 D.P. the measurement over the wires should be $\frac{28.4315}{12} = 2.3693$ inches. If the actual measurement is 2.3650 inches, the pitch diameter of the gear is $2.3693 - 2.3650 = 0.0043$ inch undersize.

An odd-toothed external gear of 35 teeth, 16 diametral pitch, 20-degree pressure angle is measured with 0.108 inch diameter wires which, when placed in the gear, are not diametrically opposite by ½ tooth interval. From Table 4 the measurement for 1 D.P. is 37.3802 inches. For 16 D.P. the measurement over the wires should be $\frac{37.3802}{16} = 2.3363$ inches.

An odd-toothed internal gear of 51 teeth, 8 diametral pitch, 20-degree pressure angle is measured with 0.180 inch diameter wires which, when placed in the gear, are not diametrically opposite by a ½-tooth interval. From Table 6 the measurement between the wires for 1 D.P. is 49.6409 inches. For 8 D.P. the measurement between the wires should be $\frac{49.6409}{8} = 6.2051$ inches.

Allowance for Backlash

The measurements over the wires given in the following tables are for gears of the theoretical standard size, or without backlash.

Backlash, space, or play is often specified in a pair of mating gears in order to provide for permissible tolerances in the pitch diameter and in the shape or thickness of the gear teeth. A certain amount of backlash will insure that the gears will operate at their proper center distances. Backlash may be defined as the shortest distance between the nondriving surfaces of mating gears.

Backlash is provided by cutting the teeth thinner or, what amounts to the same thing, by reducing the pitch diameter of the gear. In the majority of cases, the teeth of both mating gears are cut thinner by one-half of the total backlash desired. Where very small pinions are used, all of the backlash is often obtained on the

TABLE 2.—GEAR WIRE SIZES

D.P.	Wire Diameter for External Gears $G = \frac{1.728}{D.P.}$ in Inches	Wire Diameter for Internal Gears $G = \frac{1.44}{D.P.}$ in Inches
2	0.864	0.720
2½	0.6912	0.576
3	0.576	0.480
4	0.432	0.360
5	0.3456	0.288
6	0.288	0.240
7	0.24686	0.20571
8	0.216	0.180
9	0.192	0.160
10	0.1728	0.144
11	0.15709	0.13091
12	0.144	0.120
14	0.12343	0.10286
16	0.108	0.090
18	0.096	0.080
20	0.0864	0.072
22	0.07855	0.06545
24	0.072	0.060
28	0.06171	0.05143
32	0.054	0.045
36	0.048	0.040
40	0.0432	0.036
48	0.036	0.030
64	0.027	0.0225
72	0.024	0.020
80	0.0216	0.018

These gear-measuring wires are $1\frac{7}{8}$ inches long and are held within 25 millionths of an inch for roundness and exact size.

They are standardized at 1 pound pressure between flat measuring contacts.

NOTE:—The Fellows stub tooth is expressed as a fractional D.P., such as $\frac{7}{9}$. The numerator 7 represents the D.P. that is used for figuring the circular pitch and the pitch diameter, and the denominator 9 is the D.P. that is used to figure the addendum and the dedendum. A 7 D.P. gear wire should therefore be used for a $\frac{7}{9}$ D.P. Fellows gear.

TABLE 3.—EXTERNAL GEARS. EVEN TEETH

Measurements over Wires for 1 D.P. External Spur Gears with Wires $\frac{1.728}{D.P.}$ Inches in Diameter

For Any Other Diametral Pitch, Divide Measurements Given in the Tables by the Diametral Pitch

All Measurements in Inches

No. of Teeth	14½ Degrees	17½ Degrees	20 Degrees	25 Degrees	30 Degrees
6	8.2847	8.2927	8.3020	8.3298	8.3751
8	10.3160	10.3196	10.3266	10.3505	10.3918
10	12.3400	12.3396	12.3445	12.3658	12.4038
12	14.3590	14.3552	14.3578	14.3768	14.4123
14	16.3746	16.3677	16.3680	16.3847	16.4173
16	18.3877	18.3780	18.3765	18.3908	18.4216
18	20.3989	20.3866	20.3837	20.3958	20.4254
20	22.4086	22.3940	22.3899	22.4000	22.4287
22	24.4171	24.4004	24.3953	24.4036	24.4315
24	26.4247	26.4060	26.4000	26.4067	26.4339
26	28.4315	28.4110	28.4040	28.4094	28.4359
28	30.4376	30.4154	30.4074	30.4118	30.4376
30	32.4431	32.4193	32.4103	32.4139	32.4391
32	34.4481	34.4228	34.4128	34.4157	34.4404
34	36 4526	36.4259	36.4150	36.4173	36.4416
36	38.4567	38 4287	38.4171	38.4187	38.4427
38	40.4604	40.4313	40.4191	40.4200	40.4437
40	42.4638	42.4337	42.4211	42.4212	42.4446
42	44.4669	44.4359	44.4231	44.4223	44.4454
44	46.4698	46.4380	46.4250	46.4233	46.4462
46	48.4726	48.4400	48.4268	48.4243	48.4469
48	50.4753	50.4419	50.4284	50.4252	50.4476
50	52.4779	52.4437	52.4298	52.4261	52.4482
52	54.4804	54.4454	54.4310	54.4269	54.4487
54	56.4827	56.4470	56.4320	56.4277	56.4492
56	58.4848	58.4485	58.4329	58.4284	58.4497
58	60.4867	60.4499	60.4337	60.4291	60.4501
60	62.4885	62.4512	62.4345	62.4297	62.4506
62	64.4902	64.4524	64.4353	64.4303	64.4510
64	66.4918	66.4535	66.4361	66.4309	66.4514
66	68.4933	68.4545	68.4369	68.4314	68.4517
68	70.4948	70.4554	70.4377	70.4319	70.4520
70	72.4963	72.4562	72.4384	72.4324	72.4523
72	74.4977	74.4570	74.4391	74.4328	74.4526
74	76.4990	76.4577	76.4397	76.4332	76.4529
76	78.5002	78.4584	78.4403	78.4335	78.4532
78	80.5014	80.4591	80.4409	80.4338	80.4534
80	82.5026	82.4598	82.4414	82.4341	82.4536
82	84.5037	84.4604	84.4419	84.4344	84.4538
84	86.5047	86.4610	86.4424	86.4347	86.4540
86	88.5057	88.4616	88.4429	88.4350	88.4542
88	90.5067	90.4622	90.4434	90.4353	90.4544

TABLE 3.—EXTERNAL GEARS. EVEN TEETH.—*Continued*

No. of Teeth	14½ Degrees	17½ Degrees	20 Degrees	25 Degrees	30 Degrees
90	92.5076	92.4628	92.4438	92.4356	92.4546
92	94.5085	94.4634	94.4442	94.4359	94.4548
94	96.5094	96.4640	96.4446	96.4362	96.4550
96	98.5102	98.4646	98.4450	98.4364	98.4552
98	100.5110	100.4652	100.4454	100.4366	100.4554
100	102.5118	102.4657	102.4457	102.4368	102.4555
102	104.5126	104.4662	104.4460	104.4370	104.4557
104	106.5134	106.4667	106.4463	106.4372	106.4558
106	108.5142	108.4672	108.4466	108.4374	108.4560
108	110.5149	110.4677	110.4469	110.4376	110.4561
110	112.5156	112.4681	112.4471	112.4378	112.4562
112	114.5162	114.4685	114.4474	114.4380	114.4563
114	116.5167	116.4689	116.4477	116.4382	116.4564
116	118.5172	118.4693	118.4480	118.4384	118.4565
118	120.5177	120.4697	120.4483	120.4386	120.4566
120	122.5182	122.4701	122.4486	122.4388	122.4567
122	124.5187	124.4705	124.4489	124.4390	124.4569
124	126.5192	126.4708	126.4492	126.4391	126.4571
126	128.5197	128.4711	128.4494	128.4392	128.4572
128	130.5202	130.4714	130.4496	130.4393	130.4574
130	132.5207	132.4717	132.4498	132.4394	132.4575
132	134.5212	134.4720	134.4500	134.4395	134.4577
134	136.5217	136.4723	136.4502	136.4396	136.3578
136	138.5222	138.4726	138.4504	138.4397	138.4580
138	140.5226	140.4729	140.4506	140.4398	140.4581
140	142.5230	142.4732	142.4508	142.4399	142.4582
142	144.5234	144.4734	144.4510	144.4400	144.4582
144	146.5238	146.4736	146.4512	146.4401	146.4582
146	148.5242	148.4738	148.4514	148.4402	148.4583
148	150.5246	150.4740	150.4516	150.4403	150.4583
150	152.5250	152.4742	152.4518	152.4404	152.4583
152	154.5254	154.4744	154.4520	154.4405	154.4583
154	156.5258	156.4746	156.4522	156.4406	156.4584
156	158.5262	158.4748	158.4524	158.4407	158.4584
158	160.5265	160.4750	160.4525	160.4408	160.4584
160	162.5268	162.4752	162.4526	162.4409	162.4584
162	164.5271	164.4754	164.4527	164.4410	164.4584
164	166.5274	166.4756	166.4528	166.4411	166.4584
166	168.5277	168.4758	168.4529	168.4412	168.4584
168	170.5280	170.4760	170.4530	170.4413	170.4585
170	172.5283	172.4762	172.4531	172.4414	172.4585
180	182.5298	182.4772	182.4536	182.4419	182.4588
190	192.5310	192.4780	192.4541	192.4423	192.4591
200	202.5321	202.4786	202.4545	202.4426	202.4593
300	302.5395	302.4830	302.4575	302.4443	302.4606
400	402.5434	402.4854	402.4595	402.4453	402.4613
500	502.5444	502.4868	502.4605	502.4458	502.4619
∞	$(N+2)$.5454	$(N+2)$.4880	$(N+2)$.4615	$(N+2)$.4468	$(N+2)$.4629

Above 170 teeth, where the gear to be measured is not included in the table, use the number of teeth plus 2 for the figure to the left of the decimal point, and for the figure to the right of the decimal point interpolate between the table values. EXAMPLE.—The measurement over wires for a 1 D.P., 240-tooth, 14½-degree gear would be

$$242.5321 + \frac{40}{100} \times 0.0074 = 242.53506.$$

TABLE 4.—EXTERNAL GEARS. ODD TEETH

Measurements over Wires for 1 D.P. External Spur Gears with Wires $\frac{1.728}{\text{D.P.}}$ Inches in Diameter

For Any Other Diametral Pitch, Divide Measurements Given in the Tables by the Diametral Pitch

All Measurements in Inches

No. of Teeth	14½ Degrees	17½ Degrees	20 Degrees	25 Degrees	30 Degrees
5	6.9933	7.0036	7.0153	7.0472	7.0891
7	9.1121	9.1173	9.1260	9.1536	9.1928
9	11.1827	11.1845	11.1905	11.2142	11.2510
11	13.2317	13.2290	13.2332	13.2536	13.2880
13	15.2677	15.2600	15.2660	15.2826	15.3143
15	17.2957	17.2849	17.2870	17.3031	17.3334
17	19.3181	19.3053	19.3046	19.3181	19.3483
19	21.3365	21.3222	21.3194	21.3299	21.3603
21	23.3521	23.3364	23.3318	23.3402	23.3700
23	25.3656	25.3484	25.3423	25.3492	25.3779
25	27.3773	27.3586	27.3512	27.3570	27.3844
27	29.3875	29.3673	29.3586	29.3637	29.3899
29	31.3965	31.3748	31.3653	31.3695	31.3947
31	33.4046	33.3814	33.3709	33.3746	33.3990
33	35.4119	35.3873	35.3758	35.3791	35.4029
35	37.4185	37.3926	37.3802	37.3831	37.4064
37	39.4245	39.3974	39.3843	39.3867	39.4095
39	41.4299	41.4017	41.3881	41.3899	41.4122
41	43.4348	43.4056	43.3916	43.3928	43.4146
43	45.4394	45.4091	45.3948	45.3954	45.4167
45	47.4437	47.4123	47.3977	47.3977	47.4186
47	49.4477	49.4153	49.4004	49.3997	49.4203
49	51.4514	51.4181	51.4029	51.4015	51.4218
51	53.4548	53.4207	53.4052	53.4031	53.4242
53	55.4579	55.4231	55.4074	55.4045	55.4255
55	57.4608	57.4254	57.4094	57.4058	57.4268
57	59.4636	59.4276	59.4112	59.4070	59.4280
59	61.4663	61.4297	61.4129	61.4082	61.4292
61	63.4689	63.4317	63.4145	63.4094	63.4304
63	65.4714	65.4336	65.4160	65.4105	65.4315
65	67.4737	67.4355	67.4174	67.4115	67.4323
67	69.4758	69.4373	69.4188	69.4125	69.4334
69	71.4778	71.4391	71.4201	71.4135	71.4343
71	73.4797	73.4408	73.4213	73.4144	73.4351
73	75.4815	75.4424	75.4224	75.4153	75.4358
75	77.4832	77.4439	77.4234	77.4162	77.4365
77	79.4848	79.4453	79.4243	79.4171	79.4371
79	81.4863	81.4466	81.4252	81.4180	81.4377
81	83.4877	83.4478	83.4261	83.4188	83.4383
83	85.4891	85.4489	85.4270	85.4196	85.4389
85	87.4905	87.4499	87.4279	87.4203	87.4395
87	89.4919	89.4509	89.4288	89.4209	89.4400
89	91.4932	91.4519	91.4296	91.4215	91.4405

TABLE 4.—EXTERNAL GEARS. ODD TEETH.—*Continued*

No. of Teeth	14½ Degrees	17½ Degrees	20 Degrees	25 Degrees	30 Degrees
91	93.4945	93.4529	93.4304	93.4221	93.4410
93	95.4957	95.4538	95.4311	95.4227	95.4415
95	97 4969	97.4546	97.4318	97.4233	97.4420
97	99.4980	99.4553	99.4324	99.4239	99.4425
99	101.4990	101.4560	101.4330	101.4244	101.4430
101	103.4999	103.4567	103.4336	103.4249	103.4434
103	105.5008	105.4574	105.4342	105.4253	105.4438
105	107.5017	107.4581	107.4348	107.4257	107.4442
107	109.5026	109.4588	109.4354	109.4261	109.4446
109	111.5035	111.4595	111.4360	111.4265	111.4450
111	113.5044	113.4601	113.4365	113.4269	113.4454
113	115.5053	115.4607	115.4370	115.4273	115.4458
115	117.5062	117.4613	117.4375	117.4277	117.4462
117	119.5070	119.4619	119.4380	119.4280	119.4465
119	121.5078	121.4625	121.4385	121.4283	121.4468
121	123.5086	123.4631	123.4390	123.4286	123.4471
123	125.5093	125.4637	125.4394	125.4289	125.4474
125	127.5100	127.4643	127.4398	127.4292	127.4476
127	129.5106	129.4648	129.4402	129.4295	129.4478
129	131.5112	131.4653	131.4406	131.4298	131.4480
131	133.5118	133.4657	133.4409	133.4301	133.4482
133	135.5124	135.4661	135.4412	135.4304	135.4484
135	137.5130	137.4665	137.4415	137.4307	137.4486
137	139.5136	139.4669	139.4418	139.4310	139.4488
139	141.5142	141.4673	141.4421	141.4313	141.4490
141	143.5147	143.4676	143.4424	143.4316	143.4492
143	145.5152	145.4679	145.4427	145.4319	145.4494
145	147.5156	147.4682	147.4430	147.4322	147.4496
147	149.5161	149.4685	149.4433	149.4325	149.4498
149	151.5165	151.4688	151.4436	151.4328	151.4500
151	153.5170	153.4690	153.4439	153.4331	153.4502
153	155.5174	155.4692	155.4442	155.4334	155.4504
155	157.5179	157.4693	157.4445	157.4337	157.4505
157	159.5183	159.4694	159.4448	159.4340	159.4506
159	161.5188	161.4695	161.4451	161.4343	161.4507
161	163.5192	163.4696	163.4453	163.4346	163.4508
163	165.5196	165.4697	165.4455	165.4349	165.4509
165	167.5200	167.4698	167.4457	167.4351	167.4510
167	169.5204	169.4699	169.4459	169.4353	169.4511
169	171.5208	171.4700	171.4461	171.4355	171.4512
171	173.5212	173.4700	173.4463	173.4357	173.4513
181	183.5232	183.4730	183.4473	183.4368	183.4518
191	193.5251	193.4758	193.4483	193.4378	193.4523
201	203.5269	203.4785	203.4493	203.4388	203.4528
301	303.5344	303.4828	303.4543	303.4438	303.4574
401	403.5399	403.4852	403.4582	403.4448	403.4609
501	503.5434	503.4863	503.4592	503.4456	503.4617
∞	$(N+2)$.5454	$(N+2)$.4880	$(N+2)$.4615	$(N+2)$.4468	$(N+2)$.4629

Above 171 teeth, where the gear to be measured is not included in the table, use the number of teeth plus 2 for the figure to the left of the decimal point, and for the figure to the right of the decimal point interpolate between table values. EXAMPLE.—The measurement over wires for a 1 D.P., 335-tooth, 20-degree gear would be

$$337.4543 + \frac{34}{100} \times 0.0039 = 337.4556.$$

TABLE 5.—INTERNAL GEARS. EVEN TEETH

Measurements between Wires for 1 D.P. Internal Spur Gears with Wires $\frac{1.44}{D.P.}$ Inches in Diameter

For Any Other Diametral Pitch, Divide Measurements Given in the Tables by the Diametral Pitch

All Measurements in Inches

No. of Teeth	14½ Degrees	17½ Degrees	20 Degrees	25 Degrees	30 Degrees
6	4.8173	4.7312	4.6595	4.5206	4.3933
8	6.8270	6.7354	6.6609	6.5208	6.3950
10	8.8337	8.7380	8.6617	8.5209	8.3966
12	10.8389	10.7402	10.6623	10.5210	10.3973
14	12.8433	12.7415	12.6627	12.5210	12.3978
16	14.8470	14.7424	14.6630	14.5210	14.3982
18	16.8501	16.7432	16.6633	16.5210	16.3985
20	18.8528	18.7439	18.6635	18.5210	18.3987
22	20.8551	20.7446	20.6636	20.5211	20.3989
24	22.8570	22.7453	22.6638	22.5211	22.3991
26	24.8586	24.7459	24.6639	24.5211	24.3992
28	26.8600	26.7464	26.6640	26.5211	26.3993
30	28.8613	28.7469	28.6641	28.5211	28.3994
32	30.8624	30.7474	30.6642	30.5211	30.3995
34	32.8634	32.7478	32.6642	32.5211	32.3995
36	34.8642	34.7481	34.6643	34.5211	34.3996
38	36.8650	36.7484	36.6643	36.5211	36.3996
40	38.8657	38.7487	38.6644	38.5211	38.3997
42	40.8664	40.7490	40.6644	40.5211	40.3997
44	42.8670	42.7493	42.6645	42.5212	42.3998
46	44.8676	44.7495	44.6645	44.5212	44.3998
48	46.8682	46.7497	46.6646	46.5212	46.3999
50	48.8687	48.7499	48.6646	48.5212	48.3999
52	50.8692	50.7501	50.6646	50.5212	50.3999
54	52.8696	52.7502	52.6647	52.5212	52.4000
56	54.8700	54.7503	54.6647	54.5212	54.4000
58	56.8704	56.7504	56.6648	56.5212	56.4001
60	58.8707	58.7505	58.6648	58.5212	58.4001
62	60.8711	60.7506	60.6648	60.5212	60.4001
64	62.8714	62.7507	62.6648	62.5212	62.4001
66	64.8717	64.7508	64.6649	64.5212	64.4002
68	66.8720	66.7509	66.6649	66.5212	66.4002
70	68.8723	68.7510	68.6649	68.5212	68.4002
72	70.8726	70.7511	70.6649	70.5212	70.4002
74	72.8729	72.7512	72.6649	72.5212	72.4002
76	74.8731	74.7513	74.6649	74.5212	74.4002
78	76.8733	76.7513	76.6649	76.5212	76.4002
80	78.8735	78.7514	78.6649	78.5212	78.4002
82	80.8737	80.7514	80.6649	80.5213	80.4002
84	82.8739	82.7515	82.6649	82.5213	82.4002
86	84.8741	84.7515	84.6650	84.5213	84.4003
88	86.8742	86.7516	86.6650	86.5213	86.4003

TABLE 5.—INTERNAL GEARS. EVEN TEETH.—*Continued*

No. of Teeth	14½ Degrees	17½ Degrees	20 Degrees	25 Degrees	30 Degrees
90	88.8744	88.7516	88.6650	88.5213	88.4003
92	90.8746	90.7516	90.6650	90.5213	90.4003
94	92.8747	92.7517	92.6650	92.5213	92.4003
96	94.8749	94.7517	94.6650	94.5213	94.4003
98	96.8750	96.7518	96.6650	96.5213	96.4003
100	98.8752	98.7518	98.6650	98.5213	98.4003
102	100.8753	100.7518	100.6650	100.5213	100.4003
104	102.8755	102.7518	102.6650	102.5213	102.4003
106	104.8756	104.7519	104.6650	104.5213	104.4003
108	106.8758	106.7519	106.6650	106.5213	106.4003
110	108.8759	108.7519	108.6651	108.5213	108.4004
112	110.8760	110.7519	110.6651	110.5213	110.4004
114	112.8761	112.7519	112.6651	112.5213	112.4004
116	114.8762	114.7519	114.6651	114.5213	114.4004
118	116.8763	116.7520	116.6651	116.5213	116.4004
120	118.8764	118.7520	118.6651	118.5213	118.4004
122	120.8765	120.7520	120.6651	120.5213	120.4004
124	122.8766	122.7520	122.6651	122.5213	122.4004
126	124.8767	124.7520	124.6651	124.5213	124.4004
128	126.8767	126.7520	126.6651	126.5213	126.4004
130	128.8768	128.7520	128.6652	128.5213	128.4004
132	130.8769	130.7521	130.6652	130.5213	130.4004
134	132.8770	132.7521	132.6652	132.5213	132.4004
136	134.8771	134.7521	134.6652	134.5213	134.4004
138	136.8772	136.7521	136.6652	136.5213	136.4004
140	138.8773	138.7521	138.6652	138.5214	138.4004
142	140.8773	140.7521	140.6652	140.5214	140.4004
144	142.8774	142.7521	142.6652	142.5214	142.4004
146	144.8774	144.7521	144.6652	144.5214	144.4004
148	146.8775	146.7521	146.6652	146.5214	146.4004
150	148.8775	148.7521	148.6652	148.5214	148.4005
152	150.8776	150.7521	150.6652	150.5214	150.4005
154	152.8776	152.7521	152.6652	152.5214	152.4005
156	154.8777	154.7521	154.6652	154.5214	154.4005
158	156.8778	156.7521	156.6652	156.5214	156.4005
160	158.8778	158.7521	158.6652	158.5214	158.4005
162	160.8779	160.7521	160.6652	160.5214	160.4005
164	162.8779	162.7521	162.6652	162.5214	162.4005
166	164.8780	164.7521	164.6652	164.5214	164.4005
168	166.8780	166.7521	166.6652	166.5214	166.4005
170	168.8781	168.7521	168.6652	168.5214	168.4005
180	178.8783	178.7522	178.6653	178.5214	178.4005
190	188.8785	188.7523	188.6653	188.5214	188.4005
200	198.8787	198.7523	198.6653	198.5214	198.4005
300	298.8795	298.7525	298.6654	298.5214	298.4005
400	398.8803	398.7527	398.6654	398.5215	398.4006
500	498.8810	498.7528	498.6655	498.5215	498.4006
∞	$(N-2)$.8820	$(N-2)$.7532	$(N-2)$.6657	$(N-2)$.5216	$(N-2)$.4007

Above 170 teeth, where the gear to be measured is not included in the table, use the number of teeth minus 2 for the figure to the left of the decimal point and for the figure to the right of the decimal point interpolate between table values. EXAMPLE.—The measurement between wires for a 1 D.P., 380-tooth, 14½-degree gear would be

$$378.8795 + \frac{80}{100} \times 0.0008 = 378.88014.$$

TABLE 6.—INTERNAL GEARS. ODD TEETH

Measurements between Wires for 1 D.P. Internal Spur Gears with Wires $\frac{1.44}{\text{D.P.}}$ Inches in Diameter

For Any Other Diametral Pitch, Divide Measurements Given in the Tables by the Diametral Pitch

All Measurements in Inches

No. of Teeth	14½ Degrees	17½ Degrees	20 Degrees	25 Degrees	30 Degrees
5	3.5517	3.4752	3.4090	3.2778	3.1552
7	5.6394	5.5537	5.4823	5.3462	5.2232
9	7.6894	7.5976	7.5231	7.3847	7.2618
11	9.7219	9.6256	9.5490	9.4086	9.2866
13	11.7449	11.6454	11.5670	11.4265	11.3040
15	13.7620	13.6590	13.5801	13.4390	13.3167
17	15.7752	15.6692	15.5901	15.4486	15.3266
19	17.7857	17.6780	17.5980	17.4562	17.3345
21	19.7944	19.6854	19.6046	19.4624	19.3410
23	21.8018	21.6917	21.6099	21.4676	21.3467
25	23.8080	23.6970	23.6144	23.4719	23.3513
27	25.8133	25.7014	25.6182	25.4756	25.3551
29	27.8177	27.7050	27.6213	27.4788	27.3582
31	29.8216	29.7080	29.6240	29.4815	29.3607
33	31.8251	31.7106	31.6264	31.4841	31.3628
35	33.8283	33.7128	33.6286	33.4863	33.3645
37	35.8312	35.7147	35.6306	35.4882	35.3661
39	37.8338	37.7164	37.6325	37.4898	37.3677
41	39.8361	39.7180	39.6343	39.4912	39.3692
43	41.8382	41.7195	41.6360	41.4925	41.3706
45	43.8401	43.7209	43.6375	43.4937	43.3719
47	45.8418	45.7222	45.6388	45.4948	45.3732
49	47.8434	47.7234	47.6399	47.4958	47.3745
51	49.8449	49.7245	49.6409	49.4968	49.3757
53	51.8463	51.7256	51.6418	51.4978	51.3768
55	53.8476	53.7267	53.6426	53.4987	53.3778
57	55.8488	55.7278	55.6433	55.4995	55.3787
59	57.8499	57.7288	57.6440	57.5003	57.3796
61	59.8509	59.7297	59.6447	59.5010	59.3804
63	61.8519	61.7305	61.6454	61.5016	61.3811
65	63.8528	63.7312	63.6461	63.5022	63.3817
67	65.8536	65.7319	65.6467	65.5028	65.3822
69	67.8544	67.7326	67.6472	67.5033	67.3827
71	69.8551	69.7333	69.6477	69.5037	69.3832
73	71.8558	71.7339	71.6481	71.5041	71.3836
75	73.8564	73.7344	73.6485	73.5045	73.3840
77	75.8570	75.7349	75.6489	75.5049	75.3843
79	77.8576	77.7354	77.6493	77.5053	77.3846
81	79.8582	79.7359	79.6497	79.5057	79.3849
83	81.8587	81.7364	81.6501	81.5061	81.3852
85	83.8593	83.7368	83.6505	83.5065	83.3855
87	85.8598	85.7372	85.6508	85.5069	85.3858
89	87.8603	87.7375	87.6511	87.5072	87.3861
91	89.8608	89.7378	89.6514	89.5075	89.3864
93	91.8613	91.7381	91.6517	91.5078	91.3867

TABLE 6.—INTERNAL GEARS. ODD TEETH.—*Continued*

No. of Teeth	14½ Degrees	17½ Degrees	20 Degrees	25 Degrees	30 Degrees
95	93.8618	93.7384	93.6520	93.5081	93.3870
97	95.8623	95.7387	95.6523	95.5084	95.3873
99	97.8628	97.7390	97.6526	97.5087	97.3876
101	99.8632	99.7393	99.6529	99.5090	99.3879
103	101.8636	101.7395	101.6532	101.5093	101.3882
105	103.8639	103.7397	103.6534	103.5096	103.3885
107	105.8642	105.7399	105.6537	105.5098	105.3888
109	107.8645	107.7401	107.6539	107.5100	107.3891
111	109.8648	109.7403	109.6542	109.5102	109.3894
113	111.8651	111.7405	111.6544	111.5104	111.3897
115	113.8653	113.7407	113.6547	113.5106	113.3900
117	115.8656	115.7409	115.6549	115.5108	115.3903
119	117.8659	117.7411	117.6550	117.5110	117.3905
121	119.8662	119.7413	119.6552	119.5112	119.3907
123	121.8664	121.7415	121.6553	121.5113	121.3909
125	123.8667	123.7417	123.6555	123.5114	123.3911
127	125.8669	125.7419	125.6556	125.5115	125.3913
129	127.8671	127.7421	127.6558	127.5116	127.3915
131	129.8674	129.7423	129.6559	129.5117	129.3916
133	131.8676	131.7425	131.6561	131.5118	131.3917
135	133.8678	133.7427	133.6562	133.5119	133.3918
137	135.8680	135.7429	135.6564	135.5120	135.3919
139	137.8682	137.7431	137.6566	137.5121	137.3920
141	139 8684	139.7433	139.6568	139.5122	139.3921
143	141.8686	141.7435	141.6569	141.5123	141.3922
145	143.8688	143.7436	143.6571	143.5124	143.3923
147	145.8690	145.7437	145.6573	145.5125	145.3924
149	147.8692	147.7438	147.6574	147.5126	147.3925
151	149.8694	149.7439	149.6576	149.5127	149.3926
153	151.8696	151.7440	151.6577	151.5128	151.3927
155	153.8698	153.7441	153.6578	153.5129	153.3928
157	155.8700	155.7442	155.6578	155.5130	155.3929
159	157.8702	157.7443	157.6579	157.5131	157.3930
161	159.8704	159.7444	159.6580	159.5132	159.3931
163	161.8706	161.7445	161.6581	161.5133	161.3931
165	163.8708	163.7446	163.6582	163.5133	163.3932
167	165.8710	165.7447	165.6582	165.5133	165.3932
169	167.8712	167.7448	167.6583	167.5133	167.3933
171	169.8713	169.7449	169.6584	169.5133	169.3933
181	179.8722	179.7453	179.6587	179.5135	179.3935
191	189.8730	189.7456	189.6589	189.5137	189.3937
201	199.8737	199.7458	199.6591	199.5139	199.3939
301	299.8745	299.7466	299.6603	299.5163	299.3962
401	399.8753	399.7473	399.6615	399.5186	399.3984
501	499.8760	499.7476	499.6626	499.5212	499.4006
∞	$(N-2).8820$	$(N-2).7532$	$(N-2).6657$	$(N-2).5216$	$(N-2).4007$

Above 171 teeth, where the gear to be measured is not included in the table, use the number of teeth minus 2 for the figure to the left of the decimal point and for the figure to the right of the decimal point interpolate between table values. EXAMPLE.—The measurement between wires for 1 D.P., 337-tooth, 14½-degree gear would be

$$335.8745 + \frac{36}{100} \times 0.0008 = 335.8748.$$

large gear, and the pinion is made to standard size. This reduces undercutting of the teeth on the pinion.

The following table shows the amount R that the wire measurement should be reduced in order to provide for a desired backlash B.L.

Pressure Angle of Gears in Degrees	Equal Backlash Taken on Each Gear	All of Backlash Taken on One Gear	Amount Teeth Are Cut Too Thin (t) Approximately
14½	$R = 2 \times$ B.L.	$R = 4 \times$ B.L.	$t = \frac{R}{4}$
17½	$R = 1.66 \times$ B.L.	$R = 3.33 \times$ B.L.	$t = \frac{R}{3.33}$
20	$R = 1.46 \times$ B.L.	$R = 2.92 \times$ B.L.	$t = \frac{R}{2.92}$
25	$R = 1.18 \times$ B.L.	$R = 2.36 \times$ B.L.	$t = \frac{R}{2.36}$
30	$R = 1 \times$ B.L.	$R = 2 \times$ B.L.	$t = \frac{R}{2}$

EXAMPLE.—A total backlash of 0.016 inch is desired between two mating gears of 14½-degree pressure angle, and 0.008 inch will be taken on each gear. Then the wire measurements for each gear should be 2 × 0.016 = 0.032 inch less than the values determined from the gear tables. If all the 0.016 inch backlash is taken on one gear, the wire measurement should be 4 × 0.016 = 0.064 inch less than the value obtained from the tables.

In cutting the gear, the extra depth of cut in order to provide the desired backlash should be ½ of the reduction R in the measurement over the wires.

INTERPOLATION FOR SPECIAL PRESSURE ANGLES

Where gears of unusual pressure angles, such as 27½ degrees, are to be measured, the measurement over the wires can be secured from the proper table by interpolation. For example, the measurement over the wires for a 1 D.P. external gear, 48 teeth, and 27½-degree pressure angle would be the average between the 25-degree and 30-degree pressure-angle values from Table 3, or

$$\frac{50.4252 + 50.4476}{2} = \frac{100.8728}{2} = 50.4364 \text{ inch.}$$

Fellows stub-tooth gears may be measured with wires in the same manner as any standard 20-degree involute gears. The numerator diametral pitch should be used to determine the diameter of the wires from Table 2.

Module Gears

$$\text{Module} = \frac{\text{Pitch diameter in millimeters}}{\text{Number of teeth}}$$

Wire diameter, in mm. = 1.728 × module

Measurement over wires, in mm. = Table value × module

TABLE 7.—TABLE OF TOOTH PARTS
FELLOWS 20-DEGREE STUB GEARS

Diametral Pitch	Circular Pitch $\frac{3.1416}{\text{D.P.}}$	Thickness of Tooth at Pitch Diameter $\frac{1.5708}{\text{D.P.}}$	Addendum $\frac{1}{\text{Denominator D.P.}}$	Clearance	Dedendum (Addendum Plus Clearance)	Whole Depth to Be Cut, Spurs, Spirals
$\frac{3}{4}$	1.0472	0.5236	0.2500	0.0625	0.3125	0.5625
$\frac{4}{5}$	0.7845	0.3927	0.2000	0.0500	0.2500	0.4500
$\frac{5}{7}$	0.6283	0.3142	0.1429	0.0357	0.1786	0.3215
$\frac{6}{8}$	0.5236	0.2618	0.1250	0.0312	0.1562	0.2812
$\frac{7}{9}$	0.4488	0.2244	0.1111	0.0278	0.1389	0.2500
$\frac{8}{10}$	0.3927	0.1964	0.1000	0.0250	0.1250	0.2250
$\frac{9}{11}$	0.3491	0.1745	0.0909	0.0227	0.1136	0.2045
$\frac{10}{12}$	0.3142	0.1571	0.0833	0.0208	0.1042	0.1875
$\frac{12}{14}$	0.2618	0.1309	0.0714	0.0179	0.0893	0.1607
$\frac{18}{16}$	0.2417	0.1208	0.0625	0.0156	0.0781	0.1406
$\frac{14}{18}$	0.2244	0.1122	0.0556	0.015	0.0706	0.1262
$\frac{16}{21}$	0.1964	0.0982	0.0476	0.015	0.0626	0.1102
$\frac{18}{24}$	0.1745	0.0873	0.0417	0.015	0.0567	0.0984
$\frac{20}{26}$	0.1571	0.0785	0.0385	0.015	0.0535	0.0920
$\frac{22}{29}$	0.1428	0.0714	0.0345	0.015	0.0495	0.0840
$\frac{24}{32}$	0.1309	0.0654	0.0312	0.015	0.0462	0.0775

Elliptoid Gear Teeth.—The elliptoid gear tooth was designed by the National Broach and Machine Company to overcome the bearing of gear teeth on the ends of the teeth. The form of tooth is shown, greatly exaggerated, in Fig. 3. The actual variation

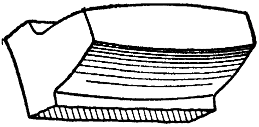


FIG. 3.—Elliptoid tooth form.

from the usual straight tooth is less than 0.0005 inch but is claimed to be sufficient to prevent end bearing and the noise arising from this cause. These gears are said to develope adequate bearing regardless of slight variations in alignment.

This form of tooth is secured by a special rocking motion of the table of the machine on which the teeth are shaved before hardening. This permits the amount of the "crown" to be regulated at will. The maximum thickness can also be located to one side of the center if desired.

TABLE *7a*.—GEAR TOOTH PARTS
Fellows 20-degree stub—modules

20-Degree Stub Tooth Modules	Circular Thickness	Addendum	Dedendum	Whole Depth of Tooth	Double Depth of Tooth
8 to 6	0.4947	0.2362	0.2952	0.5314	1.0628
7¾ to 6	0.4793	0.2362	0.2952	0.5314	1.0628
7½ to 5¾	0.4638	0.2264	0.2830	0.5094	1.0188
7¼ to 5¾	0.4484	0.2264	0.2830	0.5094	1.0188
5 to 5¼	0.4329	0.2067	0.2584	0.4651	0.9302
6¾ to 5¼	0.4174	0.2067	0.2584	0.4651	0.9302
6½ to 5	0.4019	0.1969	0.2461	0.4430	0.8860
6¼ to 4¾	0.3865	0.1870	0.2338	0.4208	0.8416
6 to 4½	0.3710	0.1772	0.2215	0.3987	0.7974
5¾ to 4½	0.3556	0.1772	0.2215	0.3987	0.7974
5½ to 4	0.3401	0.1575	0.1969	0.3544	0.7088
5¼ to 4	0.3247	0.1575	0.1969	0.3544	0.7088
5 to 3¾	0.3092	0.1476	0.1845	0.3321	0.6642
4¾ to 3½	0.2938	0.1378	0.1722	0.3100	0.6200
4½ to 3¼	0.2783	0.1279	0.1599	0.2878	0.5756
4¼ to 3¼	0.2628	0.1279	0.1599	0.2878	0.5756
4 to 3	0.2473	0.1181	0.1476	0.2657	0.5314
3¾ to 2¾	0.2319	0.1082	0.1352	0.2434	0.4868
3½ to 2½	0.2164	0.0984	0.1230	0.2214	0.4428
3¼ to 2½	0.2010	0.0984	0.1230	0.2214	0.4428
3 to 2¼	0.1855	0.0885	0.1106	0.1991	0.3982
2¾ to 2	0.1700	0.0787	0.0984	0.1771	0.3542
2½ to 2	0.1546	0.0787	0.0984	0.1771	0.3542
2¼ to 1¾	0.1391	0.0689	0.0861	0.1550	0.3100
2 to 1¾	0.1236	0.0689	0.0861	0.1550	0.3100
1¾ to 1½	0.1082	0.0591	0.0741	0.1332	0.2664
1½ to 1¼	0.0927	0.0492	0.0642	0.1134	0.2268
1¼ to 1	0.0773	0.0394	0.0544	0.0938	0.1876
1 to ¾	0.0618	0.0295	0.0374	0.0669	0.1338

Flame-Hardening of Gear Teeth.—Both the Fellows Gear Shaper Company and the Gleason Works have developed special flame-hardening apparatus for the localized hardening of gear teeth. While the former specialize on the hardening of small gears, the Gleason Works handle gears up to 120 inches pitch diameter. Gears made of any steel that can be furnace-hardened can be hardened by the flame method. It is also possible to harden cast and malleable irons of certain compositions. With steel gears the core can be given any desired heat-treatment before the teeth are flame-hardened.

SECTION VII

FORGING, FORMING, PUNCHING, AND WELDING IN AIRCRAFT WORK

LOW-COST DIES

The aircraft industry has developed several types of low cost die for punching and forming sheet metal. These are very useful where only small quantities are required.

Continental Dies.—Continental dies were developed by the aircraft industry for use where the quantity required does not warrant regular dies. Cold-rolled steel, casehardened, will punch from 100 to 150 pieces of aluminum sheet. The punch is usually attached to a guide plate, but if only a few pieces are needed it can be laid on the sheet directly over the die opening.

Magnetic Dies.—Magnetic dies are another development of the aircraft industry. The backing plates of both punch and die (which may be of any desired material) are made of magnetic metal and are held in position by magnets in both the ram and the bed of the press.

THE GUERIN FORMING PROCESS

The Guerin process for cutting and forming sheet materials is used in various aircraft plants under license from Douglas Aircraft Company as a simple method of blanking and forming many classes of airplane parts without the usual types of press tools. The work is handled in big hydraulic presses.

In place of conventional mating dies as commonly applied in power presses for stamping, drawing, etc., this process employs a single die only, a low-cost unit, and a flat thick pad of resilient material which adapts itself to a die of any form. By pressing a sheet of metal between the die and the resilient pad, it is possible to cut and form it to almost any desired shape. Deep drawing of complicated parts may be done by this process through the use of progressive operations.

It is stated that 25 sets of parts, or less, will ordinarily warrant tooling for this process. Tooling methods are simple and correspondingly inexpensive. The cutting blocks are usually $\frac{5}{16}$-inch-thick templets of the parts required. Form blocks need not be of metal unless hot forming or strictly high production is required, for either Masonite or Pregwood is satisfactory and may be made with inexpensive woodworking equipment. Metal blocks, when necessary, can be cut with the torch from steel or sawed from aluminum or magnesium alloy plate or fabricated from cast metal, such as zinc, Kirksite, and scrap aluminum or magnesium.

Due to the uniform pressure applied by the resilient pad, local distortion is eliminated and cold-working of the metal is reduced to a minimum. Parts so produced have little or no distortion in the heat-treating processes. The resilient pad also protects the finish of the work, since there is no possibility of scratching the metal in handling through this process. Possibility of corrosion is reduced by avoiding such scratches on the work surface.

SQUARE FORMING OF METAL STAMPINGS

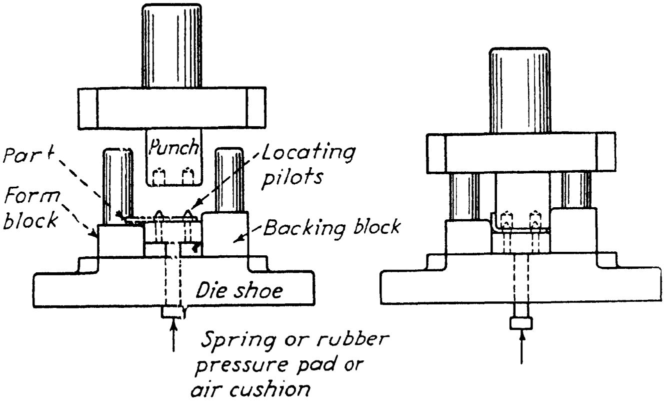
Allowances.—In forming ears and other right-angle parts on stampings, the harder the material the greater amount of "spring back" will be found in the work. This has to be offset by allowances in the press tools. The allowances shown here are recommended by Walter Kassebohm. One-quarter hard cold-rolled steel has approximately 1 to 2 degrees spring back; one-half hard has approximately 3 to 4 degrees; hard steels have, in most instances, more than 5 degrees spring back; and annealed spring steel has as high as 15 to 20 degrees spring back.

The Pad Form Die.—In general with dies where simple V tools cannot be used, the pad form die, as shown in Fig. 1, is best known and is very satisfactory. As illustrated, the part to be formed is located by nests or pilot pins on the pad of the form die. At the downstroke of the press, the part is held between the punch and pad of the die and is formed up, as shown in Fig. 2. The forms thus obtained are deformations of the metal which are exceeding the elastic limit, thus remaining in the formed-up condition after the punch is releasing the part at the upstroke of the press.

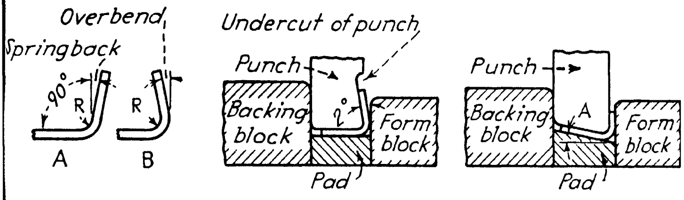
Figure 3 shows at *A* a part formed up to exactly 90 degrees in the form die. The part shows a decided spring back, the amount of which depends on the characteristics of the metal from which the part is made and on the radius *R* in the corner of the bend. If the part had been "overbent" in the form die, as illustrated at *B* (Fig. 3), it would have been a square-formed part after being removed from the form die, since the spring back would compensate for the overbend.

There are several ways of accomplishing a compensation for spring back in a form die. Figure 4 shows an undercut of the punch, which allows the part to overbend. Since the spring back, after the part is removed from the form die, is the same amount as the overbend, the part will have an exact 90-degree form.

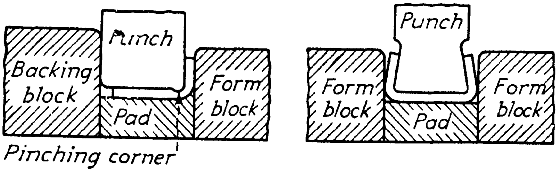
Figure 5 shows a die that overbends the part by having the punch and pad of the form die ground with angular surfaces. The angle *A* is the amount of overbending and is to be found again by trial. Two-degree angular surface is again a good dimension for forming one-quarter hard cold-rolled steel, which is sometimes called C, or No. 3, temper stock, and possesses approximately 70 to 75 Rockwell B scale hardness.



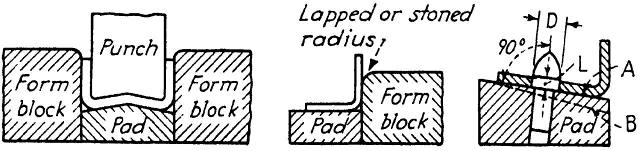
Pad form dies.



Spring back in formed work.



Two types of punches.



Other methods.

Figs. 1–10.—Square forming of metal stampings.

Figure 6 shows another method of getting square-formed parts. The bottom of the punch is ground and possesses a slightly higher surface in the corner, which gives the metal a greater "setting" during the forming, therefore destroying elasticity of the metal and consequent spring back. Since with this method the structure of the metal loses certain desired strength qualities, this method should be eliminated as much as possible.

U Bends.—The method of forming a square corner U bend is shown in Fig. 7 and is practically the same as in Fig. 4, using an undercut punch. Another U bend method is shown in Fig. 8 and is largely the same as Fig. 5, the double angle being found by trial.

It is very important in the making of a good working form die that the corner over which the part is formed be highly polished. Figure 9 shows the radius, which should be lapped or stoned to a very highly polished surface, thus allowing the part to be formed without galling up or scratching. The polishing of the radius should be done in the direction of the bend and not in the lengthwise direction of the form block. In case of a U form, it is important that the radii on both form blocks be the same. A small radius on one form block and a large radius on the other form block would cause a side strain on the part, as well as on the punch, allowing variations and inaccuracies in the form.

Parts are sometimes located on a form pad of a form die by pilots, and if the pad has an angular surface for a compensating forming operation, the pilot should be located at a vertical (90-degree) position to this surface, as shown in Fig. 10. Any appreciable tilting of the pilot caused by regrinding of the angular surface should be corrected by regrinding or reestablishing the pilot hole in the pad. This will put the pilot again in a vertical position to the angular surface.

The best forms, without breakage or cracks in the corner, are obtained with one-quarter hard, or No. 3 (sometimes also called "C" temper), cold-rolled strip steel, which bends 150 degrees "across" the grain, or at a sharp angle of 90 degrees "with" the grain, without showing any marks of failure. One-half hard, or No. 2 temper stock, will allow a sharp bend "across" the grain, but "with" the grain only a bend with a large radius can be made without showing signs of failure. Hard, or No. 1 temper, stock, is mostly used for flat work without forms. Any forming of this stock should always be done "across" the grain, and with a very large radius in the corner.

SOFT-METAL PUNCHES AND DIES

The use of soft-metal punches and dies was developed in aircraft shops for drawing small quantities of sheet-metal parts. Dies of zinc and punches of lead answer the purpose but are short-lived. An alloy of aluminum, copper, magnesium, and zinc, known as Kirksite, is lighter, harder, and stronger, and is used for the dies. Cerro-matrix is also used for dies. It has a melting point about

250°F. It is made by the Cerro de Pasco Copper Company. Cerrobase melts at 255°F. and Cerroben at 158°F. This is used to fill small tubes for bending. It melts in boiling water.

Punches of lead with from 6 to 10 per cent of antimony are still used, but where the work is severe Kirksite is also used for the punch. Its life is from three to five times that of lead.

FORGING ALUMINUM ALLOYS

The increased use of aluminum alloy forgings in warplane construction makes the following suggestions by the Douglas Aircraft Company of particular value. The formula is made to estimate the size of steam hammer necessary to make forgings of different sizes. It includes the actual area of the forging itself at the parting line, and the area of the smallest rectangle that will completely enclose the cross section of the piece to be forged, at the parting line. The two areas are multiplied together. The size of steam hammer necessary to forge parts with these areas multiplied together is given below.

When the Actual Area Times the Rectangular Enclosing Area in Square Inches Is	The Work Requires This Size of Hammer
Up to 150	2,000-pound board
150 to 700	2,000-pound steam
700 to 13,000	3,000-pound steam
13,000 to 40,000	6,000-pound steam
40,000 to 113,000	18,000-pound steam
113,000 to 240,000	25,000-pound steam
Over 240,000	35,000-pound steam

If the part has a large amount of thin web or has corners and edge radii much below the usual sharpness, the next larger size hammer may be required.

Time for Changing Die Sets.—One large airplane builder has fixed time allowance for setup and teardown of drop-hammer die sets as follows: For die sets weighing less than 1,000 pounds, 19 minutes; from 1,000 to 4,000 pounds, 24 minutes; for dies over 4,000 pounds, 32 minutes.

Aluminum Materials Formed by Drop Hammers.—The common alloys used in drop-hammer forming are: 3SO, 3S½H, 24SO, 24SO Alclad, 52SO, and 52S½H. Where certain parts are to be thickened (or shrunk) 3SO is better than 3S½H. When extreme stretch and thickening are needed, use 2SO.

Alclad (aluminum alloy with a coating of pure aluminum) works well, the aluminum coating acting as a lubricant. Hard stock, such as 24ST and 24ST Alclad, is rarely used in drop-hammer drawing.

Work-Hardening.—Such alloys as 2SO and 3SO work-harden very little. But 24SO, 52SO, and 52S½H work-harden rapidly. Quick annealing by dipping in lead at 640 to 650°F. gives a uniform "draw" of the work.

Aluminum Forging Temperatures.—Maximum temperatures for drop forging aluminum alloys are as follows:

Alloy	Degrees Fahrenheit	Alloy	Degrees Fahrenheit
14S	840	A51S	880
17S	840	53S	880
18S	820*	70S	840
25S	860	73S	820
32S	800*		

* These may be heated to 880 or 900°F. when forged in a press or an upsetting machine.

Draft.—For drop forging dies 7° is recommended. Forging presses require only ¼ degree, upsetters 1 degree.

Beeswax is a good lubricant for dies forging aluminum.

Forging Hammer Foundations.—Experience suggests making the foundations for drop hammers *twice* the weight of the hammer itself.

WELDING

Tube Welding for Maximum Strength.—The A. O. Smith Company has developed a method of arc welding tubular and similar structures to secure maximum strength. The thickness of metal at the weld is increased by having the tube go over the mating member, as at *A* (Fig. 11), leaving a gap for the metal of the weld. Similar results are obtained by reinforcing the upset ends of the tubes with a ring beneath the weld. Table 1 gives the proportions of the various parts of the mating parts that have given best results.

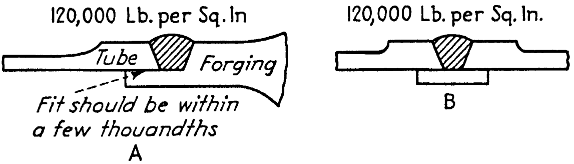
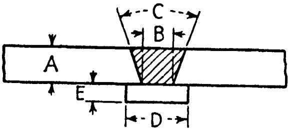


FIG. 11.—Welded joints.

Atomic Hydrogen Welding.—Atomic hydrogen welding is the procedure in which the arc is usually drawn between two electrodes that are surrounded by hydrogen gas to exclude air. The welding rod is fed into the arc. This has been found more satisfactory in most cases than drawing the arc between the welding rod and the work.

TABLE 1.—DIMENSIONS FOR HIGH-STRENGTH WELDED JOINTS



A	*B*	*C*	*D*	*E*
$\frac{1}{8}$	$\frac{3}{16}$	60°	$\frac{5}{8}$	$\frac{1}{8}$ to $\frac{5}{32}$
$\frac{3}{16}$	$\frac{3}{16}$	60	$\frac{5}{8}$	$\frac{1}{8}$ to $\frac{5}{32}$
$\frac{1}{4}$	$\frac{5}{16}$	60	$\frac{5}{8}$	$\frac{3}{16}$
$\frac{5}{16}$	$\frac{5}{16}$	60	$\frac{5}{8}$	$\frac{3}{16}$
$\frac{3}{8}$	$\frac{5}{16}$	40	$\frac{5}{8}$	$\frac{3}{16}$
$\frac{1}{2}$	$\frac{3}{8}$	40	$\frac{3}{4}$	$\frac{3}{16}$
$\frac{5}{8}$	$\frac{3}{8}$	30	$\frac{3}{4}$	$\frac{3}{16}$
$\frac{3}{4}$	$\frac{7}{16}$	20	1	$\frac{1}{4}$
1	$\frac{7}{16}$	20	1	$\frac{1}{4}$
$1\frac{1}{4}$	$\frac{7}{16}$	15	1	$\frac{1}{4}$
$1\frac{1}{2}$	$\frac{7}{16}$	15	1	$\frac{1}{4}$

Heliarc Welding.—Heliarc welding is a method developed by the Northrop Aircraft Company for welding magnesium. It uses a tungsten electrode for drawing the arc with the casting that is being welded and utilizes a welding rod held in the hand. The arc is direct current. The electrode is enclosed in a tube through which pure helium gas is blown to surround the arc and exclude the air.

WIDTH OF KERF IN FLAME CUTTING

Thickness of metal affects the width of kerf in cutting with oxyacetylene torch. Beginning with a minimum kerf of $\frac{5}{64}$ inch for $\frac{1}{4}$-inch plate, the usual kerf increases slowly to $\frac{1}{4}$ inch for a 12-inch depth of cut. Roughly, it increases about $\frac{1}{64}$ inch for each inch of plate thickness. The speed of cutting decreases more slowly. Taking 20 inches per minute as the cutting speed for $\frac{1}{4}$-inch plate, 2-inch plate can be cut at about 10 inches per minute, 6-inch plate at half this rate, and a fairly regular decrease up to plates of 12 inches in thickness.

TUMBLING WORK

Recent Practice.—Proper tumbling has many intricate problems because there are so many variables involved. These include the results desired; the materials to be tumbled, their size and shape; the abrasives and other materials used; the shape and speed of the tumbling barrels; the length of time and whether to use wet or dry tumbling.

Taking Catalin as an example, it has been found that wet tumbling is best when articles are very rough. A 10- to 15-gallon keg or a square barrel of soft wood with end-over-end motion is suggested. Do not load above the center line in any tumbling. Barely cover the contents with a solution of 4 ounces of FFF pumice to 12 quarts of water. For heavier work add 2 quarts of 1-inch-diameter gravel. Run 30 r.p.m. for 1 hour for a good matte finish. Makers of tumbling barrels can give much valuable information on tumbling different materials.

Dry Tumbling.—Well-machined parts rarely need wet tumbling. Use hexagon- or octagon-shaped barrels running 30 r.p.m. from 5 to 12 hours. Use 3 parts pegs, 2 parts of articles being tumbled, 1 cup FFF pumice, 1½ cups paraffin or flushing oil. Clean with kerosene-soaked sawdust (2 quarts kerosene to 12 quarts coarse hardwood sawdust) in a small barrel running over and over for 5 minutes. Use about one-half sawdust and one-half articles. Sawdust can be used more than once. Every tumbling job presents its own problem. The National Cash Register Co., Dayton, Ohio, has made a careful study of tumbling parts of various sizes and materials.

ZYGLO METHOD OF DETECTING CRACKS

The Magnaflux Corp. have developed a method of detecting crack in any material, magnetic or nonmagnetic, known as *Zyglo.* The work is dipped in a special Zyglo penetrant, or it is brushed or sprayed on the work. Then the piece is rinsed to remove surface material. Dry parts are placed in a tank and are dusted with a powder. When examined under a "black light" the penetrant powder becomes fluorescent whenever it has entered a crack or cavity, and shows defects very plainly.

SECTION VIII

INSPECTION

GAGES

Tolerances of Gages.—Interchangeable manufacture must allow for the gage maker's variations as well as for the wear of the gages. The chart shows the wear allowances and the gage maker's tolerances approved by the United States Ordnance department. For component tolerances not given the next smaller tolerance should be used. Column 1 shows the total tolerance of the product, column 2 the wear allowance on the "go" gage, column 3 the tolerance on the "go" gage, and column 4 the tolerance on the "not go" gage. There is no wear allowance on the "not go" gage because it wears toward the "go" gage and in the direction of safety.

Glass Gages.—Shortage of gage steel led to the substitution of glass at the Frankford Arsenal, and the results have been favorable. Among the gages made were plain "go" and "not go" gages, plain double-end gages, ring gages both "go" and "not go," combination ring and snap gages, profile and position gages, chamfer gages, and certain types of flush-pin gages.

Two groups of these gages are shown in Figs. 1–6. Glass plug gages have the front or entering end beveled at 30 degrees to prevent chipping.

Lt. Col. J. A. Stone, Executive Officer at the Frankford Arsenal, cites the following advantages of glass gages:

1. In the production of glass gages there is a saving of tool steel.
2. Glass gages afford visibility in inspection.
3. Extended use of glass gages will release for other production machine-hours and man-hours now consumed in annealing, machining, heat-treating, and eliminating distortion of steel gages.
4. Glass gages are not subject to corrosion.
5. Since glass gages do not rust, greasings and degreasings necessary for steel gages during shipment and storage are eliminated.
6. Because thermal conductivity of glass is less than steel, body heat of inspectors will not be transmitted so rapidly to the gage to affect gaging dimensions.
7. Scratches and slight chipping on glass neither burr glass gages nor change their gaging functions.
8. Where the part being inspected is very near the size of the gage, there is less tendency for it to seize or gall on glass than on steel.
9. Sense of feel is more pronounced when using a glass gage.

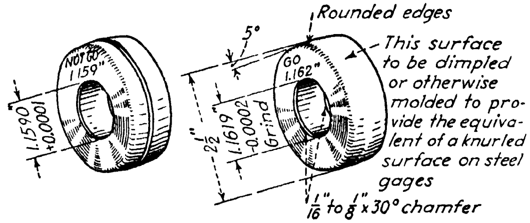

Rounded edges
This surface to be dimpled or otherwise molded to provide the equivalent of a knurled surface on steel gages
5°
NOT GO 1.159"
1.1590" +0.0001
GO 1.162"
2½"
1.1619" -0.0002
Grind
1/16" to 1/8" x 30° chamfer

FIG. 1.—Glass ring gages.

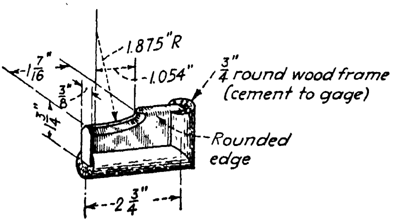


FIG. 2.—Glass contour gage.

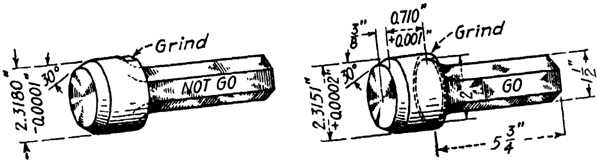


FIG. 3.—Fuse-nose gages.

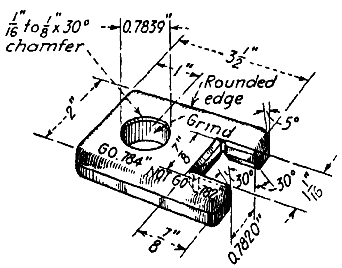


FIG. 4.—Glass snap and hole gage.

10. The use of glass will teach inspectors to handle gages carefully.

11. Glass appears to have better abrasion-resisting qualities than steel for gaging applications.

12. When a steel gage is dropped it may spring or deform, and its gaging functions may thereby be impaired. A glass gage either breaks or it remains dimensionally unchanged.

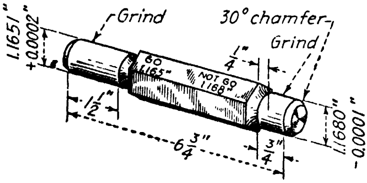


FIG. 5.—Glass "go" and "not go" gages.

It is interesting to note that surface plates are now being made from glass, marble, and granite, instead of only from cast iron as formerly.

Gage makers' tolerances are given in Table 1.

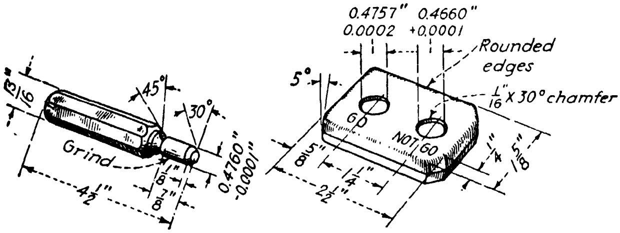


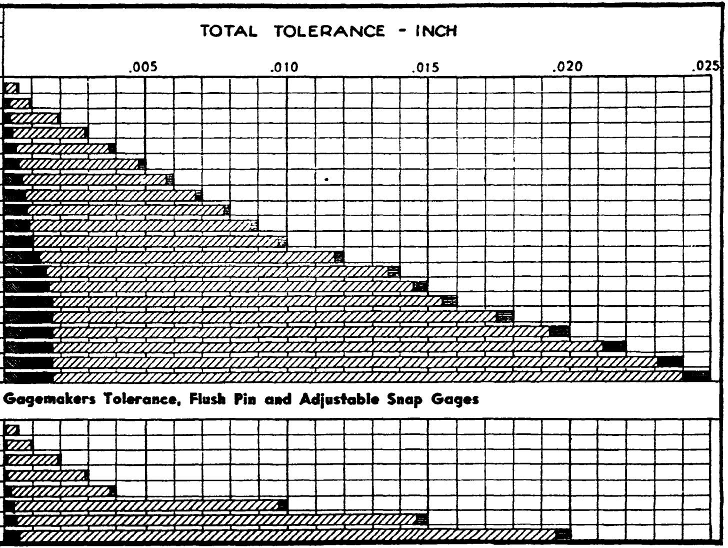
FIG. 6.—Glass plug and hole gages.

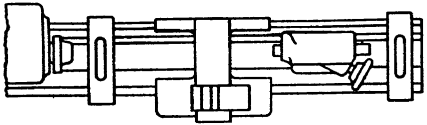
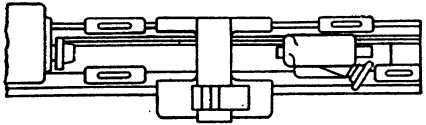
LATHE TOLERANCES

Inspection is such a vital part of war matériel that we give the latest data regarding gages for Ordnance Department work and the American Standards Association standard inspection for engine lathes. These were adopted in May, 1941. The latter is of special value in view of the large number of lathes that will require reconditioning after the war to fit them for peacetime work.

TABLE 1.—WEAR ALLOWANCES AND GAGE MAKERS' TOLERANCES

COMPONENT	GAGE		
TOTAL TOLERANCE	WEAR ALLOWANCE	TOLERANCE	
		GO	NOT GO
▨	▨	■	▤
.0005	0000	.00005	.00005
.001	.0001	.0001	.00005
.002	.0001	.0001	.0001
.003	.0001	.0002	.0001
.004	.0002	.0002	0002
.005	.0003	.0002	.0002
.006	.0004	.0002	.0002
.007	.0004	.0003	.0002
.008	.0005	.0003	.0002
.009	.0005	.0004	.0002
.010	.0005	.0005	.0003
.012	.0006	.0006	.0003
.014	.0006	.0008	.0004
.015	.0006	.0009	.0005
.016	.0006	.0010	.0005
.018	.0006	.0010	.0006
.020	.0006	.0010	.0007
.022	.0006	.0010	.0008
.024	.0006	.0010	.0009
.025 AND UP	.0006	.0010	.0010
Gagemakers Tolerance, Flush Pin and Adjustable Snap Gages			
.0005		.00005	.00005
.001		.00005	.00005
.002		.0001	.0001
.003		.0001	.0001
.004		.0002	.0002
.010		.0003	.0003
.015		.0004	.0004
.020 AND UP		.0005	.0005



Test	Recommended standards		
	Toolroom lathes	12- to 18- in., inclusive, engine lathes	20- to 36- in., inclusive, engine lathes
1  Bed level-transverse direction	When using precision level, both readings to be within 0.0005 in 12 in.	When using precision level, both readings to be within 0.0005 in 12 in.	When using precision level, both readings to be within 0.001 in 12 in.
2  Bed level-longitudinal direction	When using precision level along bed, maximum reading to be within 0.0005 in 12 in.	When using precision level along bed, maximum reading to be within 0.0005 in 12 in.	When using precision level along bed, maximum reading to be within 0.001 in 12 in.

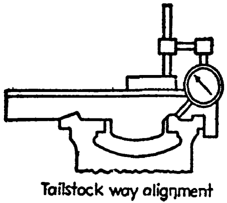
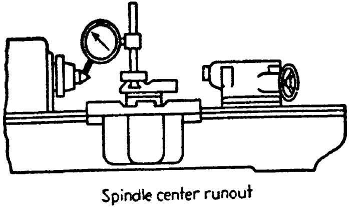
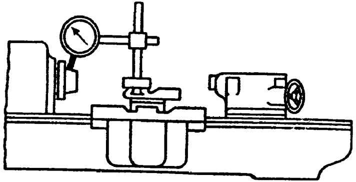
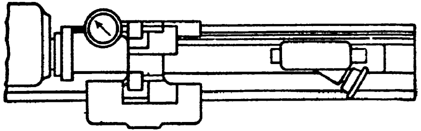
3 	Maximum reading along length of bed, 0.0005 in 48 in.	Maximum reading along length of bed, 0.00075 in 48 in.	Maximum reading along length of bed, 0.001 in 48 in.
4 	Total indicator reading, 0 to 0.0004	Total indicator reading, 0 to 0.0005	Total indicator reading, 0 to 0.00075

FIG. 1.—Accuracy of engine lathes.

Test	Recommended standards		
	Toolroom lathes	12- to 18-in., inclusive, engine lathes	20- to 36- in., inclusive, engine lathes
5  Spindle nose runout	Total indicator reading, 0 to 0.0003	Total indicator reading, 0 to 0.0004	Total indicator reading, 0 to 0.0006
6  Cam action of spindle	Total indicator reading with indicator on rear side of test plate, 0 to 0.0003	Total indicator reading with indicator on rear side of test plate, 0 to 0.0005	Total indicator reading with indicator on rear side of test plate, 0 to 0.00075

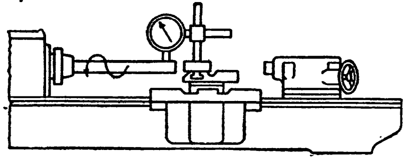
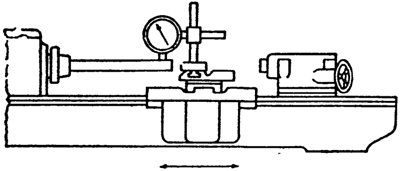
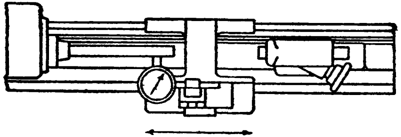
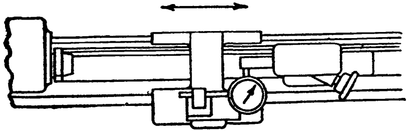
7  Spindle taper runout	Total indicator reading at end of 12-in. test bar, 0 to 0.0006; at end of spindle nose, 0 to 0.0003	Total indicator reading at end of 12-in. test bar, 0 to 0.0008; at end of spindle nose, 0 to 0.0004	Total indicator reading at end of 12-in. test bar, 0 to 0.00125; at end of spindle nose, 0 to 0.0006
8  Headstock alignment-vertical	High at end of 12-in. test bar, 0 to 0.0005	High at end of 12-in. test bar, 0 to 0.001	High at end of 12-in. test bar, 0 to 0.001

FIG. 1.—Accuracy of engine lathes.—*Continued.*

Test	Recommended standards		
	Toolroom lathes	12- to 18-in., inclusive, engine lathes	20- to 36-in., inclusive, engine lathes
9  Headstock alignment-horizontal	At end of 12-in. test bar, 0 to ±0.0003	At end of 12-in. test bar, 0 to ±0.0005	At end of 12-in. test bar, 0 to ±0.0008
10  Tailstock spindle alignment-horizontal	Forward at end of spindle when fully extended, 0 to 0.0005	Forward at end of spindle when fully extended, 0 to 0.0005	Forward at end of spindle when fully extended, 0 to 0.0005

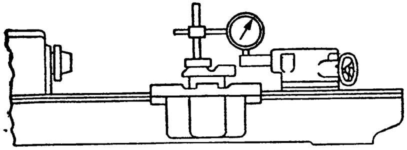
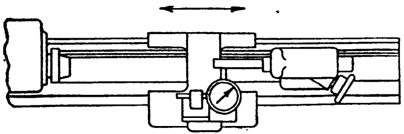
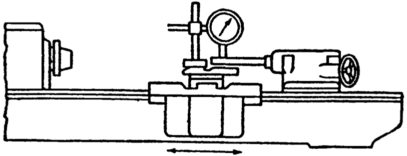
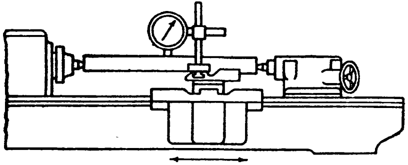
11  Tailstock spindle alignment-vertical	High at end of spindle when fully extended, 0 to 0.0005	High at end of spindle when fully extended, 0 to 0.0008	High at end of spindle when fully extended, 0 to 0.0015
12  Tailstock taper alignment-horizontal	End of 12-in. test bar, 0 to ±0.0005	End of 12-in. test bar, 0 to ±0.0008	End of 12-in. test bar, 0 to ±0.0015

FIG. 1.—Accuracy of engine lathes.—*Continued.*

Test	Recommended standards		
	Toolroom lathes	12- to 18-in., inclusive, engine lathes	20- to 36-in., inclusive, engine lathes
13  Tailstock taper alignment-vertical	High at end of 12-in. test bar, 0 to 0.0005	High at end of 12-in. test bar, 0 to 0.0008	High at end of 12-in. test bar, 0 to 0.0015
14  Vertical alignment of head & tail ctr's.	High at tailstock, 0 to 0.0008	High at tailstock, 0 to 0.001	High at tailstock, 0 to 0.0015

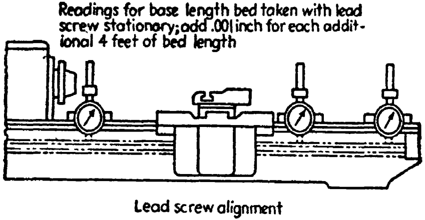
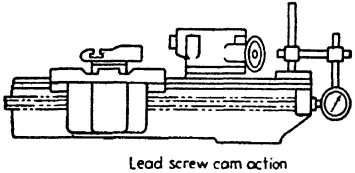
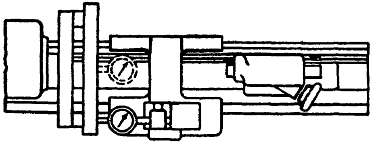
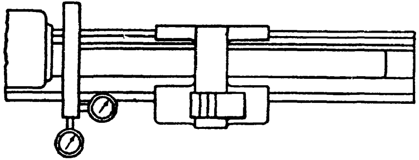
15  Readings for base length bed taken with lead screw stationary; add .001 inch for each additional 4 feet of bed length Lead screw alignment	Parallel with ways, 0 to 0.004 horizontal 0 to 0.004 vertical. Alignment of half nut horizontal or vertical, 0 to 0.006	Parallel with ways, 0 to 0.004 horizontal 0 to 0.004 vertical. Alignment of half nut horizontal or vertical, 0 to 0.006	Parallel with ways, 0 to 0.006 horizontal 0 to 0.006 vertical. Alignment of half nut horizontal or vertical, 0 to 0.008
16 	Maximum, 0.0003	Maximum, 0.0004,	Maximum, 0.0005

FIG. 1.—Accuracy of engine lathes.—*Continued.*

Test	Recommended standards		
	Toolroom lathes	12- to 18-in., inclusive, engine lathes	20- to 36-in., inclusive, engine lathes
17  Cross slide alignment	To face hollow or concave only on 12-in. diameter, 0 to 0.0005	To face hollow or concave only on 12-in. diameter, 0 to 0.001	To face hollow or concave only on 12-in. diameter, 0 to 0.001
18  Face plate run out	On diameter, 0 to 0.0005. On face at nominal diameter, 0 to 0.001	On diameter, 0 to 0.001. On face at nominal diameter, 0 to 0.0015	On diameter, 0 to 0.0015. On face at nominal diameter, 0 to 0.002

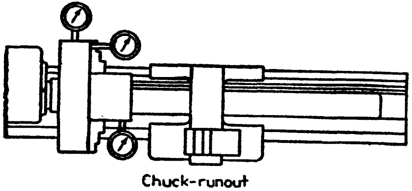
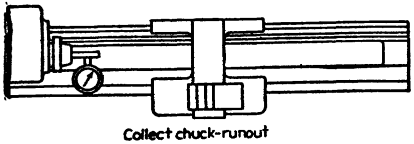
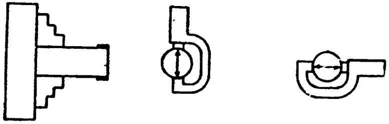
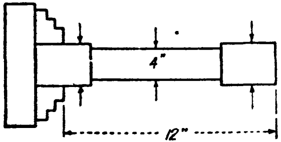
19 	Face and periphery, 0.003. Face of steps, 0.003. Bar test 3 in. from end of jaw, bar diameter same as hole, 0.003	Face and periphery, 0.003. Face of steps, 0.003. Bar test 3 in. from end of jar, bar diameter same as hole, 0.003	Face and periphery, 0.004. Face of steps, 0.004. Bar test 3 in. from end of jaw, bar diameter same as hole, 0.004
20 	1 in. from spindle, 0 to 0.001	1 in. from spindle, 0 to 0.001	1 in. from spindle, 0 to 0.001

FIG. 1.—Accuracy of engine lathes.—*Continued.*

Test	Recommended standards		
	Toolroom lathes	12- to 18-in., inclusive, engine lathes	20- to 36-in., inclusive, engine lathes
21 Lathe must turn round with work mounted in chuck 	0.0003	0.0004	0.0008
22 Lathe must turn cylindrical with work mounted in chuck 	0.0008	0.0015	0.002

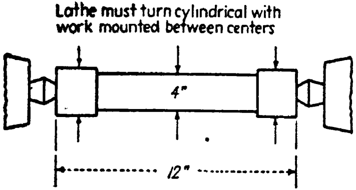
23  Lathe must turn cylindrical with work mounted between centers 4" 12"	0.0004	0.0008	0.001
24 Lead—screw lead per foot Lead in any 4 in.	 ±0.001 ±0.0004	 ±0.0015 ±0.0005	 ±0.002 ±0.0007
25 Backlash on cross-fed screw Backlash on compound-rest screw	 0.004 0.004	 0.004 0.004	 0.005 0.005

FIG. 1.—Accuracy of engine lathes.—*Continued.*

HYDRAULIC SYSTEMS ON MACHINE TOOLS

Increasing use of hydraulics for power and feeds of machine tools makes it necessary to know the factors that affect operation. According to John Sasso, oils should be checked for viscosity, stability, pour point, flash point, corrosive tendencies, emulsification, and foaming.

Testing Oils.—Viscosity is a measure of the internal friction—with too high a viscosity, excessive fluid friction causes heating, loss of power, and sluggish action. Stability is ability of the oil to resist decomposition over a period of time. Such decomposition results in gummy deposits on valves and moving parts, causing sticking and jerky operation. Pour point indicates the oil behavior at low temperatures, at which it becomes viscous enough to cause trouble. Flash point is the measure of the fire risk; in an open system the temperature at which the oil gives off inflammable vapors in an important consideration.

When an oil is easily emulsified, the frothy mixture that results is compressible; this will cause errors in amount of ram and valve motion. Emulsification increases if certain compounds of sulphur, soaps, fatty oils, and organic acids are present. If the oil level is low, the foam may cause oil to be lost by "bubbling over," uncovering pump suction and allowing air to enter the system.

Faulty lubrication caused by thin oil is usually shown by inability of the system to develop and hold desired pressures, overheating of the pump, or a reduction in power output. Noisy operation and lack of positiveness in the drive indicate lack of oil and presence of air or gasified oil mixtures.

Recommendations.—Only highly refined oils entirely free of abrasive or contaminating foreign matter should be used. High demulsibility, or water-separation ability, is not always essential, unless the system is subject to water leakage. On the other hand, low oxidizing and low carbon residue-forming tendencies are important characteristics.

Manufacturers' viscosity recommendations usually range from 140 to 1,200 seconds Saybolt at 100°F., depending on the make of pump. High pumping pressures and operating temperatures will call for heavier oils, the range depending upon the type of system. Oilgear recommends an oil of approximately 320 seconds Saybolt universal viscosity at 100°F. for general service, and lighter oils of 140 viscosity where temperatures between 30 and 45°F. prevail. Hele-Shaw suggest oil of approximately 1,000 seconds Saybolt at 100°F. for maximum-pressure operations or high temperature. The Waterbury hydraulic system requires an oil of medium viscosity, about 320 seconds Saybolt at 100°F.

TABLE 2.—HYDRAULIC-SYSTEM DIFFICULTIES AND REMEDIES

Machine Characteristics	Oil Characteristics	Remedy
Slows down on temperature rise	Oil too light	Use heavier oil to reduce leakage in pump, motor, cylinder, etc.
Erratic action, foaming or aeration of oil	Poor demulsibility, high surface tension of oil—Oil has absorbed moisture	Use oil with proper demulsibility
Sluggish	Viscosity too high	Use viscosity specified by manufacturer when sluggish at temperature, especially on starting, use low-pour-point oils
Corrosion of hydraulic system parts	Too high in acidity, oil may be compounded of harmful ingredients	Specify acid-free mineral oil, neutralization number of 0.10 maximum for combined acidity, saponifiables less than 1 per cent
Sticking valves (hydraulic)	High oxidation, oil not properly refined	Check operating temperature. Do not exceed 140 to 160°F. for best results. If temperature is satisfactory change to stable high index oil
Excessive leakage	Oil too light and/or viscosity index too low; also loose connections or excessive clearances	Tighten all connections and check clearances. If leakage is still excessive, use heavier or higher index oil
Pump noisy	Oil viscosity too high, causing excessive pressure drop in intake line, or intake line too small, creating excessive oil velocities	Use higher index or lighter oil. Use oil of lower pour point. Check pump intake size and install larger line if necessary

The data in Table 2 are an extension of the table appearing on page 559 of the "American Machinists' Handbook." The sizes given are now in use, having been developed during the war.

SECTION IX

METAL-CUTTING SAWS

HACK AND BAND SAWS

The experience of different makers and different users of metal-cutting saws does not always agree. New conditions of operation and new mixtures of metals have their effect on recommended practice. The following data are recommendations from a well-known maker of saws for metal, Henry Disston & Sons, Inc.

POWER-HACK-SAW BLADES

TABLE 1.—TO OBTAIN GREATER EFFICIENCY AND MAKE HACK-SAW BLADES LAST LONGER

Failure	Cause	Correction
Pulling out at pinhole	Blade drawn too tight	Reduce tension on blade. Allow just enough to hold it straight and prevent twisting
	Blade twisting in cut	
Premature wear	Feed too heavy	Reduce; see Table 2
	Speed too great	Reduce to recommended speed
	Incorrect tooth spacing	Use number of teeth recommended for material
	Insufficient feed	Increase feed as recommended
	Dry cutting	Use coolant
Stripping teeth	Tooth spacing too coarse	Use number of teeth recommended for material
	Teeth too fine for material	

TABLE 1.—TO OBTAIN GREATER EFFICIENCY AND MAKE HACK-SAW BLADES LAST LONGER.—*Continued*

Failure	Cause	Correction
Crooked cuts	Worn frame	Check machine for wear and adjustment
	Frame out of line with vise	
	Blade loose in frame	Adjust
	Stock not tight in vise	Inspect clamps and tighten
	Feed too heavy	Reduce; see Table 2
	Worn-out blade	Install new blade
	Hard spot in material	Start new cut. May require new blade
Blades breaking	Insufficient tension	Make adjustment
	Tooth spacing too coarse	Use number of teeth recommended for material
	Feed too heavy	Reduce; see Table 2
	New blade in unfinished cut	Start new cut
	Side strain on blade	Worn out. Change blade

TABLE 2.—RECOMMENDATIONS FOR CUTTING SPECIFIC MATERIALS WITH HACK-SAW BLADES

Material	Number of Teeth per Inch	Strokes per Minute	Feed, in Pounds
Aluminum	4 to 6	135 to 150	60
Brass, cast:			
Soft	6 to 10	135 to 150	60
Hard	6 to 10	135	60
Cast iron	6 to 10	135	120
Copper	6 to 10	135	120
Tool steel	4 to 6 to 10	90	120
Cold-rolled steel	4 to 6	135	150
High-speed steel	6 to 10	90	120
Machine steel	4 to 6	135	150
Iron pipe	10 to 14	135	120
Structural steel	6 to 10	135	120
Tubing:			
Steel	14	135	60
Brass	14	135	60

FLEXIBLE-BACK METAL BAND SAWS

TABLE 3.—TO OBTAIN GREATER EFFICIENCY AND MAKE FLEXIBLE-BACK METAL BAND SAWS LAST LONGER

Failure	Cause	Correction
Stripping teeth	Tooth spacing too coarse	Use recommended spacing
	Starting cut at extremely thin section of material or on a corner	Start cut where several teeth will contact material at same time
Premature wear and loss of set	Speed too fast	Reduce; see Table 5
	Rubbing in guides Riding on wheels	Adjust so that teeth project beyond guides—also so that teeth project over edge of wheels
Breaking	Twisting in the cut	If irregular cutting, use proper width saw for radius
	Misalignment of guides	Adjust so that top and bottom guides are in alignment
	Guides set too far apart, allow band to twist	Always adjust guides as close as possible to piece being cut
	Insufficient tension	Adjust tension to approximately 300 pounds per inch of saw width
	Allowing band to remain in tension when not in use	Remove saw from machine or release tension. Where extreme differences of temperature occur, this practice will prevent breakage
Cutting out of line	Misalignment of guides	Adjustment should be made
	Spacing of guides	Set as close as possible
	Set worn on one side due to contact with wheels or guides	Adjust so that teeth project beyond guides—also so that teeth project over edge of wheels
	Feed too heavy	Reduce feed or use coarser tooth saw

TABLE 4.—RECOMMENDED BAND-SAW WIDTHS

Width of Band Saw, Inch	Minimum Radius to Be Cut, Inches
1/16	3/32
3/32	3/16
1/8	1/4
3/16	7/16
1/4	3/4
3/8	1 1/2
1/2	2 1/4
5/8	3
3/4	4 1/2
1	8

TABLE 5.—RECOMMENDATIONS FOR CUTTING SPECIFIC MATERIALS WITH HARD-EDGE FLEXIBLE-BACK METAL-CUTTING BAND SAWS

Material	Number of Teeth per Inch	Speed of Blade, in Feet per Minute
Aluminum:		
Solids	8 to 10	800 to 2500
Sheets	8 to 10	1000 to 3000
Aluminum alloys:		
Solids	8 to 10	100 to 150
Irregular shapes	12 to 14	200 to 300
Asbestos sheets	8 to 12	150 to 200
Babbitt	10 to 14	1000 to 1500
Bakelite	8 to 10	800 to 1000
Brass castings:		
Soft	10 to 14	700 to 1500
Hard	10 to 14	200 to 500
Brass sheets and tubing	14 to 18	700 to 1500
Bronze:		
Bars	10 to 14	150 to 350
Castings	10 to 14	300 to 800
Mouldings	14 to 18	500 to 1000
Cast iron	12 to 14	100 to 125
Catalin	12 to 14	700 to 800
Copper	8 to 12	500 to 1000
Copper—nickel	12 to 14	70 to 90
Everbright	10 to 12	150 to 350
Everdur	10 to 12	150 to 350
Fiber	8 to 10	300 to 500
Formica	8	300 to 500
Hose—canvas and rubber	8 to 10	500 to 1000
Hose—metallic	18 to 24	250 to 500
Inconel	10 to 12	70 to 90
Iron bars	12 to 14	100 to 125
Iron sheets (under $\frac{1}{32}$-inch)	14 to 18	100 to 250
Metal wood	12 to 14	300 to 750
Mica	10 to 12	300 to 600
Micarta	8	300 to 500
Monel metal	10 to 12	100 to 150
Nickel silver	18 to 24	100 to 150
Pipe	14 to 18	100 to 200
Radiator core	18 to 24	150 to 400
Rubber—hard	10 to 14	150 to 200
Slate	10 to 14	100 to 150
Steel:		
Chromium	12 to 14	90 to 125
Cold-rolled	10 to 12	100 to 125
Drill rod	14	100 to 125
Heat-resistant	12 to 14	90 to 125
High-speed	12 to 14	90 to 125
Machinery	10 to 14	100 to 125
Manganese	10 to 12	90 to 100
Nickel	10 to 14	90 to 125
Structural	10 to 14	90 to 125
Tool	12 to 14	100 to 125
Tubing	14 to 18	100 to 150
Textolite	8	300 to 500
Transite	8 to 12	100 to 200

HAND HACK-SAW BLADES

TABLE 6.—TO OBTAIN GREATER EFFICIENCY AND MAKE HAND HACK-SAW BLADES LAST LONGER

Failure	Cause	Correction
Pulling out at pin hole	Blade too tight	Reduce tension. Allow just enough to hold blade straight and prevent twisting
	Blade twisting in cut	
Stripping teeth	Tooth spacing too coarse	Use number of teeth recommended for material
Blades breaking	Insufficient tension	Make adjustment
	Tooth spacing too coarse	Use number of teeth recommended
	New blade in unfinished cut	Start new cut
	Side strain on blade	Do not bend frame sideways
	Twisting blade	Use firm straight stroke
Premature wear	Pressure on back stroke	Lift slightly on back stroke
	Insufficient pressure	Cut slowly with pressure on forward stroke

TABLE 7.—RECOMMENDATIONS

NUMBER OF TEETH PER INCH	KIND AND TYPE OF MATERIAL
14	For materials equivalent to 1-inch round or more—aluminum, brass, bronze, cast iron, copper, cold-rolled steel, structural steel, rails, etc.
18	For materials $\frac{1}{4}$ to 1 inch in diameter. Also tool steels, drill rod, cold-rolled steel and medium-weight structural shapes.
24	For materials $\frac{1}{8}$ to $\frac{1}{4}$ inch in thickness. Also pipe and tubing, BX cable, heavy sheet metal, moldings, etc.
32	For materials less than $\frac{1}{8}$ inch in thickness. Also tubing, BX cable, sheet metal, moldings, etc.

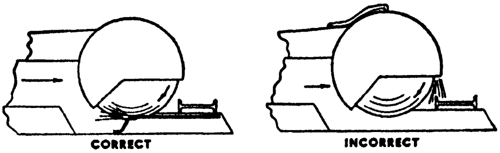
NOTE: It is suggested that blades of the flexible type be used where the operator is required to assume an awkward position, such as on a ladder. This situation often confronts electricians, plumbers, and garage mechanics.

High-Speed Band Saws.—Bell Aircraft Company runs band saws for metal at 12,000 feet per minute—8,000 feet per minute for wood. They are carbon-steel blades and cut any metal up to armor plate, also glass. They are really hot saws, according to Arthur A. Schwartz, chief tool research engineer. The teeth heat the work, and the oxygen carried in between the teeth burns the metal, as with torch cutting.

On thick metal it is necessary to feed oxygen into the cut, the same as with torch cutting.

FRICTION DISKS AND HOT SAWS

TABLE 8.—TO OBTAIN GREATER EFFICIENCY AND MAKE HOT SAWS LAST LONGER


CORRECT INCORRECT

Failure	Cause	Correction
Cracking	Insufficient speed	Should run at 22,000 to 25,000 feet per minute rim speed
	Improper water-supply	Cooling waters should be applied at point where rim of saw leaves cut. Pressure should be at least 90 to 150 pounds—preferably 300 pounds
	Slipping on spindle	Tighten arbor nut
Picking up or loading of teeth	Insufficient speed	Should be 22,000 to 25,000 feet per minute
	Lack of feed power	Supply sufficient power to force saw through material as fast as possible
	Improper water supply	Apply as recommended to keep blade as cool as possible. Also, prevent water from touching hot work

Data regarding hot saws, band saws and files are from Henry Disston & Sons, Inc.

TABLE 9.—TO OBTAIN GREATER EFFICIENCY AND LONGER LIFE FROM FRICTION DISKS

Failure	Cause	Correction
Cracking	Insufficient speed	Should run at 22,000 to 25,000 feet per minute rim speed
	Improper water supply	Cooling water should be applied at point where rim of saw leaves cut. Pressure should be at least 90 to 150 pounds—preferably 300 pound
	Slipping on spindle	Tighten arbor nut
Picking up or loading of hobbed or nicked rim	Insufficient speed	Should be 22,000 to 25,000 feet per minute
	Lack of feed power	Have sufficient power to force saw through material as fast as possible
	Improper water supply	Apply as recommended to keep blade cool and allow material to heat to a red color. Prevent water from reaching the work

CIRCULAR AND BAND SAWS FOR PLASTICS[1]

TABLE 10.—NARROW BAND SAWS FOR CUTTING PLASTICS

Failure	Cause	Correction
Cracks in gullets	Saw too thick for wheel diameter	Choose saw of gage to suit wheel diameter. See recommendation chart
	Rubber bands worn, allowing uneven strain	Replace the worn rubber bands
	Teeth set too deep, allowing blade distortion	Adjust set
	Dull teeth	Braze saw where cracked, if possible. Keep sharp, using recommended band-saw taper file
	Teeth incorrectly shaped	Braze saw where cracked, if possible. Face of each tooth should be radial—no hook or rake Set first, then file straight through with high corner on outside
Saw stretched	Too much pressure against back guide	Replace saw; adjust back guide so back edge of saw merely touches when material is fed to saw
Saw not holding to line	Not correctly strained on wheels	See Table 1 for correct amount of strain
	Saw too thin or too narrow for material being cut	Select saw of the correct thickness and width for the material to be cut
	Incorrect adjustment of guides	Place the upper guide in a position to just clear work; the bottom guide as close as possible to bottom of saw table. Adjust guide pins on both guides to just clear sides of saw back of the set line
Broken teeth	Setting anvil bevel too sharp	Round off sharp angle. Joint and refit saw to bring broken teeth to even length
Breakage at braze	Braze made improperly or poorly finished	Brazed portion of the saw should be of the same thickness as the balance of the saw. Too thin, saw is weak at the joint; if too thick, saw will hang up in the guides. After finishing braze, heat slightly to restore temper

NOTE: When gullets are cracked, first take care of correction to prevent recurrence; then braze saw where cracked when practicable, and sharpen. Do not operate a saw that is cracked.

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[1] Unless otherwise specified, the saws covered in Tables 10 to 13 are tensioned for a rim speed of 10,000 feet per minute.

TABLE 11.—HOLLOW-GROUND, SOLID-TOOTH CIRCULAR PLASTIC SAWS

Failure	Cause	Correction
Cracks in gullets	Incorrect tension for operating speed	Check mandrel speed. Replace cracked saw with one of correct tension
	Casehardening in gullets	Replace cracked saw. Avoid casehardening by light grinding with soft wheel
	Dull teeth	Replace cracked saw. Keep teeth sharp and corners prominent
	Incorrect lead or rake to teeth	Replace with new saw. Study the job. Some plastics require teeth with positive rake; others require teeth with slight negative rake; others should have teeth with radial face
	Incorrect thickness and incorrect teeth	Replace cracked saw. For thin work use a thin-gage saw with fine teeth; for thick work use a coarser tooth, heavier saw
Overheating	Usually insufficient clearance. Dull teeth	As saw is reduced in diameter, the side clearance is also lessened. Have saw reground with correct clearance. Resharpen
Leading in the cut	Teeth incorrectly sharpened	For plastics, teeth should be sharpened straight across—no bevel either on face or back of teeth. For softer plastics, suggest bevel on face and back of teeth alternately. Be sure all teeth are the same height
	Saw too thin for the work	If a thin saw must be used, feed slowly. A thicker saw is recommended for thick hard plastics; a thinner saw may be used on thinner material, especially on the softer plastics

TABLE 12.—GAGE OF SAW TO SIZE OF WHEEL

Size of wheel, in inches...	12	16	18	20	24	30	36	42
Gage of saw............	26	24	24	22	22	22	21	20

TABLE 13.—BAND-SAW TENSION OR STRAIN

Width of blade, in inches........	⅛	¼	⅜	½	⅝	¾	⅞	1	1¼
Tension, in pounds..	25	55	100	160	200	240	280	320	440

MACHINISTS' FILES

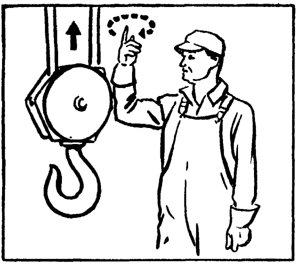
TABLE 14.—HOW TO OBTAIN GREATER EFFICIENCY AND MAKE MACHINISTS' FILES LAST LONGER

Failure	Cause	Correction
Stripping teeth	Choppy or fast filing stroke	Use long, steady, uniform stroke
	Too coarse a file for the job; or using wrong file	Use finer cut.
	Too much pressure	A new file bites into the work more easily. File lightly at first
	Work held improperly	Work to be filed should be held tightly in vise
Premature wear	Improper pattern, size, or cut of file	Refer to Table 15
	Dragging file on return stroke	Raise file slightly on return stroke
	Filing too fast (or running work in lathe too fast)	Use long, steady, uniform stroke. Reduce speed so file does not slide or glaze
	Too much pressure	Ease up on filing stroke
	File clogging	Refer to recommended file and cut and use file card and brush
	Rusty files	Protect file when not in use
	Careless handling	Respect your file as a cutting tool and treat it accordingly
Breakage	Cleaning file by knocking against vise or work	Use file card and brush
	Careless handling	Do not drop or use as a lever for prying
	Too much pressure	On a new file apply light pressure. Ease up on filing stroke
Clogging	Improper tooth and cut	See Table 15
	Soft or tough gummy materials such as lead, aluminum, etc.	Draw the file back lightly along the metal on the return stroke so as to clean the teeth
	Too much pressure	A new file bites into the work more easily and clogs. File lightly at first
	General clogging	Use a file card and brush to remove chips that lodge in the teeth. By chalking cutting teeth, clogging can be avoided, and smoother work produced with less scoring and scratching

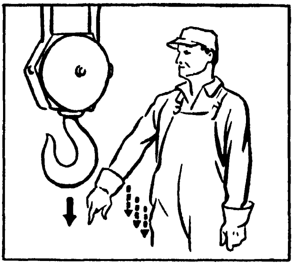
Table 15.—Guide for the Selection of the Proper File for the Job*

Roughing. Where rapid removal of metal is the object, bastard files should be selected; however, where the work is of thin gage or light stock, choose a second cut or smooth file with teeth of finer spacing, for filing across the thickness	Flat surfaces—flat, hand Holes—Round, square, three-square, half-round Corners—round, square, three-square, half-round Slots—Knife, pillar, warding
Finishing. Where work is to be smoothed or finished, select second cut or smooth files. All thin and hard materials require smooth files	Flat surfaces—Flat, hand smooth. A mill bastard or mill second cut is more desirable for a very smooth finish Lathe—Mill, flat Holes—Round, square, three-square, half-round Corners—Round, square, three-square, half-round Slots—Knife, pillar, warding.

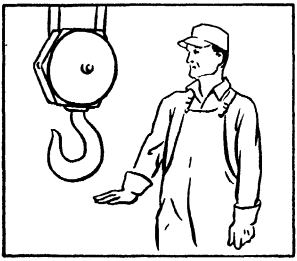
* Machine shop files are divided into three degrees of coarseness, depending upon the spacing of the teeth, into bastard as coarsest, second cut as medium coarse, and smooth as finest. With the exception of the mill, mill-lathe, and shear tooth patterns, all the files in this group are double cut.



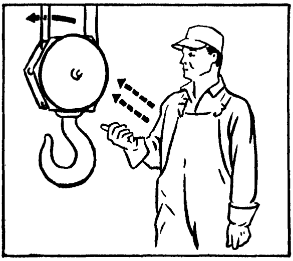
HOIST—Forearm Vertical. Make Small Horizontal Circle with the Hand.



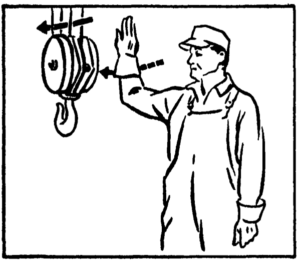
LOWER—Arm Extended. Hand Below Hip, Wave Forearm Downward.



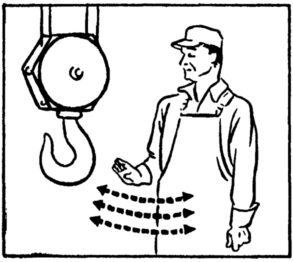
STOP—Arm Extended, Hand Level with the Hip, Hold Position Rigidly.



RACK—Arm Extended, Hand Just Above Hip, Fingers Closed, Thumb Extended Horizontally. Jerk Hand in Direction of Racking.



TRAVEL — Forearm Vertical, Hand Open. Wave Forearm in Direction of Travel.



EMERGENCY STOP—Arm Extended, Hand Level with the Hip, Wave Hand Quickly to Right and Left.

CAUTION—Crane Operators are also instructed to observe signals only from persons duly authorized for crane service, and under no circumstances to move a load until the signal is received from the proper man.

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